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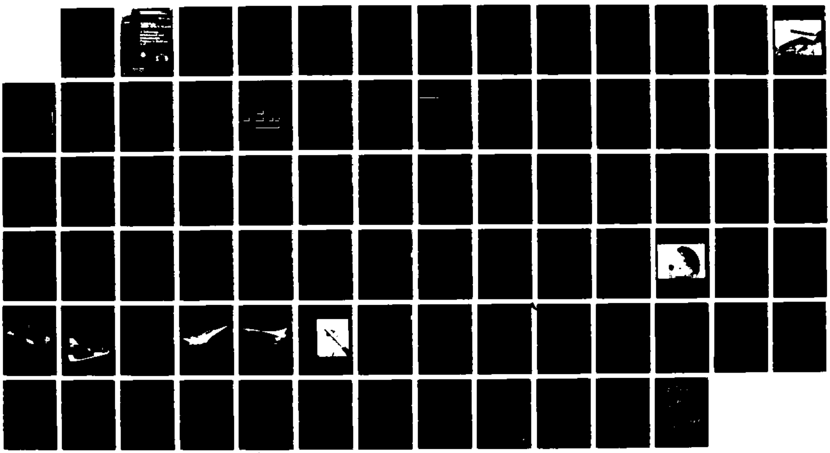

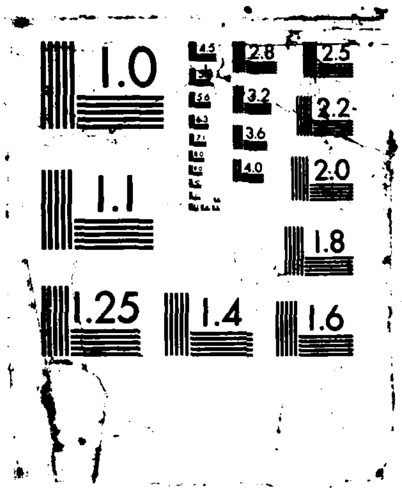
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NATIONAL AERO-SPACE PLANE

A Technology Development and Demonstration Program to Build the X-30

GAO/NSIAD-88-122

GAO United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-229301

April 27, 1988

The Honorable Sam Nunn
Chairman, Committee on Armed Services
United States Senate

The Honorable Ernest F. Hollings
Chairman, Committee on Commerce, Science,
and Transportation
United States Senate

The Honorable Les Aspin
Chairman, Committee on Armed Services
House of Representatives

The Honorable Robert A. Roe
Chairman, Committee on Science, Space,
and Technology
House of Representatives

This report describes the National Aero-Space Plane Program and provides a status of the X-30's technological development.

We are sending copies of this report to the Secretaries of Defense, Commerce, the Air Force, and the Navy; the Administrator, National Aeronautics and Space Administration; and the Directors of the Defense Advanced Research Projects Agency, Strategic Defense Initiative Organization, Office of Management and Budget, and Office of Science and Technology Policy in the Executive Office of the President.

Frank C. Conahan

Frank C. Conahan
Assistant Comptroller General

Executive Summary

Purpose

The National Aero-Space Plane (NASP) Program is a $3.3 billion joint Department of Defense (DOD)/ National Aeronautics and Space Administration (NASA) technology development and demonstration program to build and test the X-30 experimental flight vehicle. The X-30 is being designed to take off horizontally from a conventional runway, reach hypersonic speeds of up to 25 times the speed of sound, attain low earth orbit, and return to land on a conventional runway. The X-30 would fly 10 times faster and higher than existing air-breathing aircraft.

Because of widespread congressional interest in the NASP Program, GAO reviewed the National Aero-Space Plane's (1) goals and objectives, (2) program costs and schedule estimates, (3) key technological developments, integration, and risks, (4) potential military, space, and commercial mission applications, (5) program management and acquisition strategies, and (6) alternatives and international aerospace development efforts. This report describes the NASP Program and provides a status of the X-30's development.

Background

The NASP Program is expected to provide the technological basis for future hypersonic flight vehicles by developing critical or enabling technologies. The program also plans to develop a manned experimental flight vehicle—the X-30—to validate these technologies by demonstrating sustained hypersonic cruise and single-stage-to-orbit space launch capabilities.

The X-30 will be an experimental vehicle. It will not be a prototype or operational vehicle. The X-30 has no operational mission or requirements. The technologies demonstrated by the X-30, however, will have wide application.

The NASP Program will be accomplished in three phases. Phase I (1982-85), which preceded the NASP Program, defined the technical concept for an aerospace plane. Phase II (1985-90) is a program of concept validation. At the end of Phase II, a decision will be made, based on the maturity of the technologies, on whether to build and test the X-30. Phase III (1990-94) will build and test the X-30 with flight testing scheduled to begin in 1994. On the basis of the results of the NASP Program, a decision could be made in the mid-1990s on developing future operational aerospace planes. If a decision is made to develop future aerospace vehicles, a prototype military, space, or commercial hypersonic airplane and/or single-stage-to-orbit space launch vehicle could possibly be built by the late 1990s.

Results in Brief

The NASP Program is technologically challenging and a high-risk program. However, the potential payoffs are also high.

Significant technological advances and even breakthroughs have occurred in those technologies critical to the X-30. Analysis of conceptual engine designs indicates that a propulsion system for the X-30 that meets all of the program's goals can be built. However, developing the necessary materials to build the engine and demonstrating predicted engine efficiencies and component performance must also be achieved. These technologies must also be fully integrated, since the design of one component can have a large impact on the performance of another component.

Design and integration problems or setbacks could delay the program and increase its costs. According to NASP Program officials, although an increase in funding may reduce the technological risk and slippage in the program's schedule, it may not speed up technology maturation or development.

NASA plays an integral role in the NASP Program. Its personnel and facilities are integrated into the program, and cooperation and coordination exist between NASA and DOD.

In anticipation of receiving potentially high payoffs, industry has reported making significant investment thus far in the NASP Program and has identified extensive investment for the remainder of Phase II. However, NASP contractors are concerned about (1) cost-sharing with no near-term product or payoff, (2) sharing their proprietary design concepts with the U.S. government and other contractors, and (3) reporting current and projected proprietary NASP-related investments.

Potential users of a future aerospace plane probably will not develop specific missions or identify firm operational requirements until the X-30's capabilities have been demonstrated. Potential mission applications include hypersonic military aircraft, single-stage-to-orbit space launch vehicles, and commercial hypersonic transport aircraft.

The X-30 experimental vehicle is being designed to demonstrate cost-effective technologies for launching payloads into orbit. However, for some missions, existing or planned aircraft and space launch vehicles may be more cost-effective than an operational aerospace plane.

U.S. aeronautical leadership and preeminence are being challenged by foreign countries' development of operational aerospace plane technologies. The United Kingdom, France, West Germany, the Soviet Union, and Japan are each developing technologies for their own concept of an aerospace plane to provide independent access to space and to reduce costs of launching payloads into orbit.

The United States has no plans for foreign participation in developing the X-30.

GAO's Analysis

The NASP Program is dependent upon the successful development and integration of several critical or enabling technologies. The potential payoffs—future superior U.S. military aircraft, space transportation systems, and commercial hypersonic aircraft that have technical, cost, and operational advantages over existing systems as well as technological spin-off applications—are high. The program's management strategy is to reduce some risks through use of existing national assets, multiple technical approaches, competition among industry, a technology maturation program, and decision points at established program milestones.

Although the program's schedule and milestones may ultimately be achievable, they are ambitious and leave little room to accommodate potential design and integration problems or test failures. The program's goal is to design, fabricate, and flight test the X-30 by the end of fiscal year 1994. If any one of the enabling technologies does not mature as quickly as expected, the entire program could be delayed.

Congressional concern has been expressed about (1) NASA's perceived limited role in the program and the need for a major civilian component and (2) insufficient NASA contributions. DOD has responsibility for overall management of the NASP Program and plans to contribute about $183 million to the program in fiscal year 1988. GAO found that NASA's role is defined, and its personnel and facilities are integrated into the program. NASA has the major role in technology maturation and lead responsibility for developing civilian applications.

In fiscal year 1987, the Congress directed that the Secretary of Defense certify that NASA had agreed to assume a significantly larger portion of NASP research, development, test and evaluation costs. NASA subsequently increased its share of these costs by about 40 percent from 20.2 to 28.2 percent of the revised total Phase II costs between fiscal years

1986 and 1990. Even though NASA increased its investment as a percentage of total Phase II costs, the Congress inserted similar language in fiscal year 1988 legislation. In addition to NASA's fiscal year 1988 contribution of $71 million to the NASP Program, NASA plans to contribute $70 million in fiscal year 1988 in personnel and facility operation costs.

Industry has reported investing more than $353 million in the NASP Program during fiscal years 1986 and 1987 compared with the U.S. government's expenditure of $233 million appropriated for the NASP Program during that same period.

Recommendations

GAO's objectives were to describe the NASP Program and the technological challenges it faces; therefore, it makes no recommendations.

Agency Comments

DOD, NASA, the Department of Commerce, and the Office of Science and Technology Policy in the Executive Office of the President concurred with GAO's findings. Agency comments appear in full in appendixes I through IV.

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Chapter 4 What Are the Potential Uses and Alternatives for an Operational Aerospace Plane?

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Abbreviations

CARGUS	Cargo Upper Stage
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
GAO	General Accounting Office
HOPE	H-II Orbiting Plane
HORUS	Hypersonic Orbital Upper Stage
HOTOL	Horizontal Takeoff and Landing
JPO	Joint Program Office
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
PMO	Program Management Office
RST	rapid solidification technology
scramjet	supersonic combustion ramjet
SDIO	Strategic Defense Initiative Organization

Chapter 1

Introduction

The National Aero-Space Plane (NASP) Program is a $3.3 billion joint Department of Defense (DOD)/National Aeronautics and Space Administration (NASA) technology development and demonstration program to provide a technological basis for future hypersonic[1] flight vehicles by developing enabling technologies. The program plans to build and test the X-30 experimental flight vehicle to validate these technologies. The X-30 is being designed to take off horizontally from a conventional runway, reach hypersonic speeds of up to Mach 25 (25 times the speed of sound),[2] attain low earth orbit, and return to land on a conventional runway.

This report describes the NASP Program and provides a status of the X-30's technological development.

What Is the NASP Program's Objective?

The objective of the NASP Program is to develop and demonstrate the technology for hypersonic flight vehicles having technical, cost, and operational advantages over existing military and commercial aircraft and space launch systems. This critical or enabling technology includes

- an air-breathing[3] propulsion system using a supersonic combustion ramjet (scramjet);[4]
- advanced materials that are high strength, lightweight, able to withstand high temperatures, and fully reusable;
- a fully integrated engine and airframe;
- use of computational fluid dynamics[5] and supercomputers for aerodynamic, structural, and propulsion system design; and

[1]Hypersonic is that speed which is five times or more the speed of sound in air (761.5 mph at sea level). Supersonic is a range of speed between about one and five times the speed of sound in air. Transonic is a range of speed between about 0.8 and 1.2 times the speed of sound in air. Subsonic is any speed below the speed of sound in air.

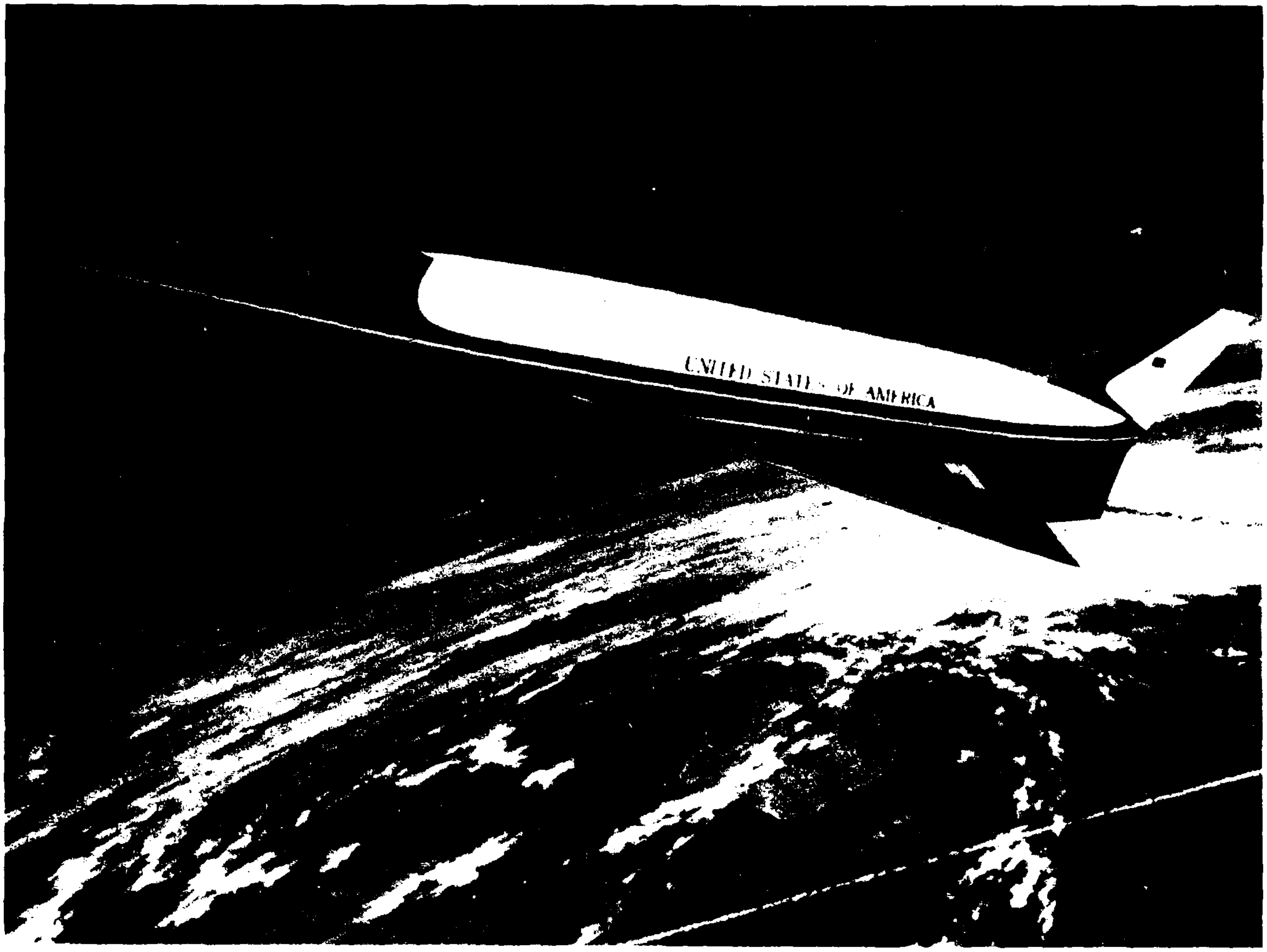
[2]Mach number refers to the ratio of the speed of an object to the speed of sound in the atmosphere. Mach 1 is the speed of sound. Because the speed of sound is a function of temperature, it varies at different altitudes.

[3]Air-breathing is an engine or aerodynamic vehicle that requires air for combustion of its fuel.

[4]A scramjet is an air-breathing engine in which air flows through the combustion chamber at supersonic speeds. Hydrogen is injected into the combustion chamber where it is ignited by the hot air. The exhaust is expelled through the nozzle, causing the thrust. Scramjets operate at speeds of about Mach 4 to 25.

[5]Computational fluid dynamics, or numerical aerodynamic simulation, is a tool for predicting the aerodynamics and fluid dynamics of air around flight vehicles by solving a set of mathematical equations with a computer. Computational fluid dynamics is used in the NASP Program to improve the understanding of hypersonic flow physics and as an aerospace plane design tool.

Figure 1.1: National Aero-Space Plane Generic Design Configuration



Source: NASA

- efficient use of hydrogen both as a fuel and a coolant to actively cool the airframe.

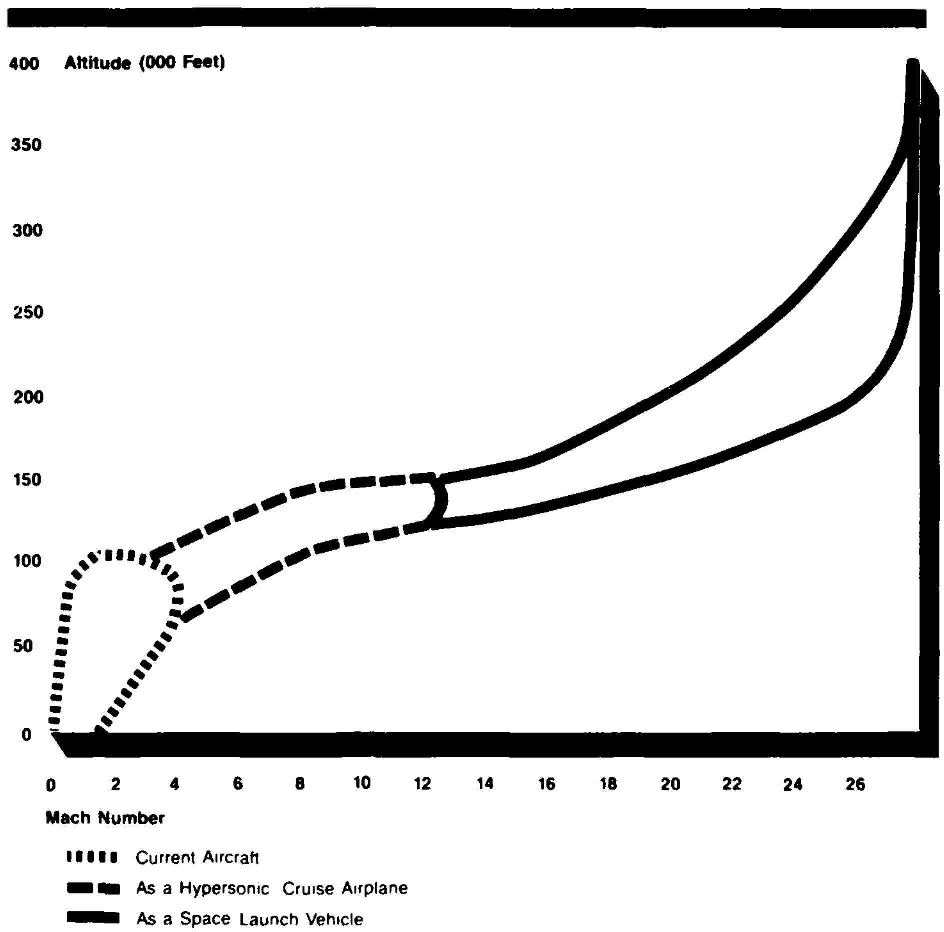
Figure 1.1 shows the NASP Program's generic design concept for the X-30.

The X-30 is expected to have an integrated engine and airframe in that the entire underside of the vehicle's forebody from the nose cone to the

scramjet serves as an air inlet for the engine. Similarly, the underside of the vehicle's afterbody from the scramjet to the tip of the tail assembly serves as the engine's exhaust nozzle. Most of the fuselage will consist of a fuel tank.

The X-30 is being designed to fly 10 times faster and higher than existing air-breathing aircraft. Figure 1.2 illustrates its potential capabilities and compares its operational limits with existing air-breathing aircraft.

Figure 1.2: Atmospheric Flight Envelopes and Trajectories for the National Aero-Space Plane as a Hypersonic Cruise Airplane and Space Launch Vehicle



The X-30 will be designed to demonstrate sustained hypersonic cruise capability in the atmosphere at speeds between Mach 5 and 14 and at altitudes between 80,000 and 150,000 feet. Current aircraft cannot operate at these speeds and altitudes primarily due to the lack of a suitable propulsion system. The X-30 is also intended to demonstrate a single-stage-to-orbit space launch capability reaching speeds of up to Mach 25—orbital escape velocity.

The X-30's flight trajectory into orbit will be different from that of the space shuttle's. Although the shuttle reaches orbit very quickly in an almost vertical flight trajectory, the X-30 would achieve speeds of Mach 25 in the upper atmosphere before making a final ascent maneuver into orbit. However, reentry into the earth's atmosphere for both the shuttle and the X-30 would generally follow the same flight trajectory. The key differences between the shuttle and the X-30 are that the X-30 (1) will use an air-breathing propulsion system instead of a separate rocket booster, (2) will not require external fuel tanks, (3) will be able to take off horizontally, and (4) will be able to make a powered landing and have maneuvering capability, if needed, during landing.

What Are the X-30's Design Goals?

According to NASP Program officials, the single-stage-to-orbit space launch capability using air-breathing propulsion is the most important and technically challenging design goal of the X-30. It also offers the highest potential payoff of NASP's technologies. If successful, this capability, in an operational space launch system, could lead to on-demand assured access to space at a significantly reduced cost-per-mission compared with the shuttle and other projected space launch systems. The key technology demonstration objectives are to achieve sufficient thrust and efficiency from the propulsion system between takeoff and speeds up to Mach 25 and to develop a lightweight airframe.

The second most important design goal is sustained hypersonic cruise capability in the atmosphere between speeds of Mach 5 and 14, allowing future hypersonic airplanes to carry out potential military missions, such as interdiction, reconnaissance, surveillance, strategic bombing, and strategic airlift, as well as potential commercial missions, such as long-haul passenger and cargo transportation.

Another key X-30 design goal is horizontal takeoff and landing from conventional runways. This capability would allow flexibility in basing a military version of a single-stage-to-orbit aerospace plane, increase basing survivability by eliminating U.S. reliance on just two principal

space launch complexes (Cape Canaveral in Florida and Vandenberg Air Force Base in California), reduce operational and support costs, and permit rapid turnaround. From a commercial perspective, a horizontal takeoff and landing capability is essential to permit operations from commerciai airports. However, a future operational aerospace plane would require some additional airport facilities such as a propellant servicing area. Supercooled liquid hydrogen fuel must be routinely and safely stored and handled; this would require additional research and development and operational costs. The X-30's technical objective for this design goal is to demonstrate high subsonic thrust from the propulsion system, which is required for operations from conventional runways.

Finally, the X-30's design goals of achieving maximum maneuvering capability for reentry into the earth's atmosphere and powered landing capability could provide flexibility for both military and commercial missions as well as increased crew and passenger safety. These capabilities could allow an operational aerospace plane to maneuver while deorbiting and landing and also allow air controllers to handle it in a similar fashion to conventional airplanes, although some special handling procedures will be required. The X-30's technical objective for this goal is to demonstrate efficient low-speed propulsion and control.

Key Cost Reduction Factors in the X-30's Design Concept as a Space Launch Vehicle

The NASP Program's primary objective is to develop and demonstrate the technology for single-stage-to-orbit space launch capability using air-breathing propulsion. To reduce significantly the costs of launching a payload into orbit, cost reduction factors have been incorporated in the X-30's design concept.

The X-30 is being designed to demonstrate reusable vehicle technologies that could result in a reusable operational vehicle rather than a refurbishable vehicle like the shuttle, thus eliminating many operational costs. For example, heat shield tiles used on the shuttle would be eliminated on the X-30, since they are costly to maintain. Further, the X-30 experimental vehicle is being designed to fly 150 times compared with 100 flights for the operational shuttle, thus increasing its usable life.

On the basis of X-30 tests, potential future aerospace vehicles are expected to have the capability of achieving quicker turnaround than the shuttle and other current launch vehicles. Horizontal takeoff and landing capability and the air-breathing propulsion system eliminate the need for a solid rocket booster or other type of launch support vehicle

that increases turnaround time. Maintenance of the X-30 is expected to be similar to that of an airplane rather than a launch booster. The X-30 is being designed to take advantage of line replaceable units or "black boxes," which could reduce line maintenance requirements and turnaround times.

The X-30's technical concept of an air-breathing hypersonic cruise airplane or single-stage-to-orbit space launch vehicle is expected to reduce costs by making it autonomous. The X-30 will not need vertical assembly buildings and launch pads or the extensive manpower-intensive logistical support required for the shuttle. It is also being designed without solid rocket boosters and external fuel tanks. The elimination of solid rocket boosters also eliminates the solid rocket propellant, which constitutes a significant part of the shuttle's weight. Instead, the X-30 will use a less costly air-breathing propulsion system and an internal hydrogen fuel tank. Launch flight operations and recovery costs should also be less than what is required for the shuttle. Overall, a future operational aerospace plane is expected to provide a greater payload per pound of vehicle and per pound of fuel used than the shuttle.

Finally, the X-30 is not expected to cruise in that region of the atmosphere where its exhaust could adversely affect the ozone layer. The X-30 is expected to use hydrogen fuel and its exhaust, which consists primarily of water vapor, is unlikely to have an adverse effect on the ozone layer. Environmental concerns are discussed in more detail in chapter 4.

What the X-30 Is—And Is Not

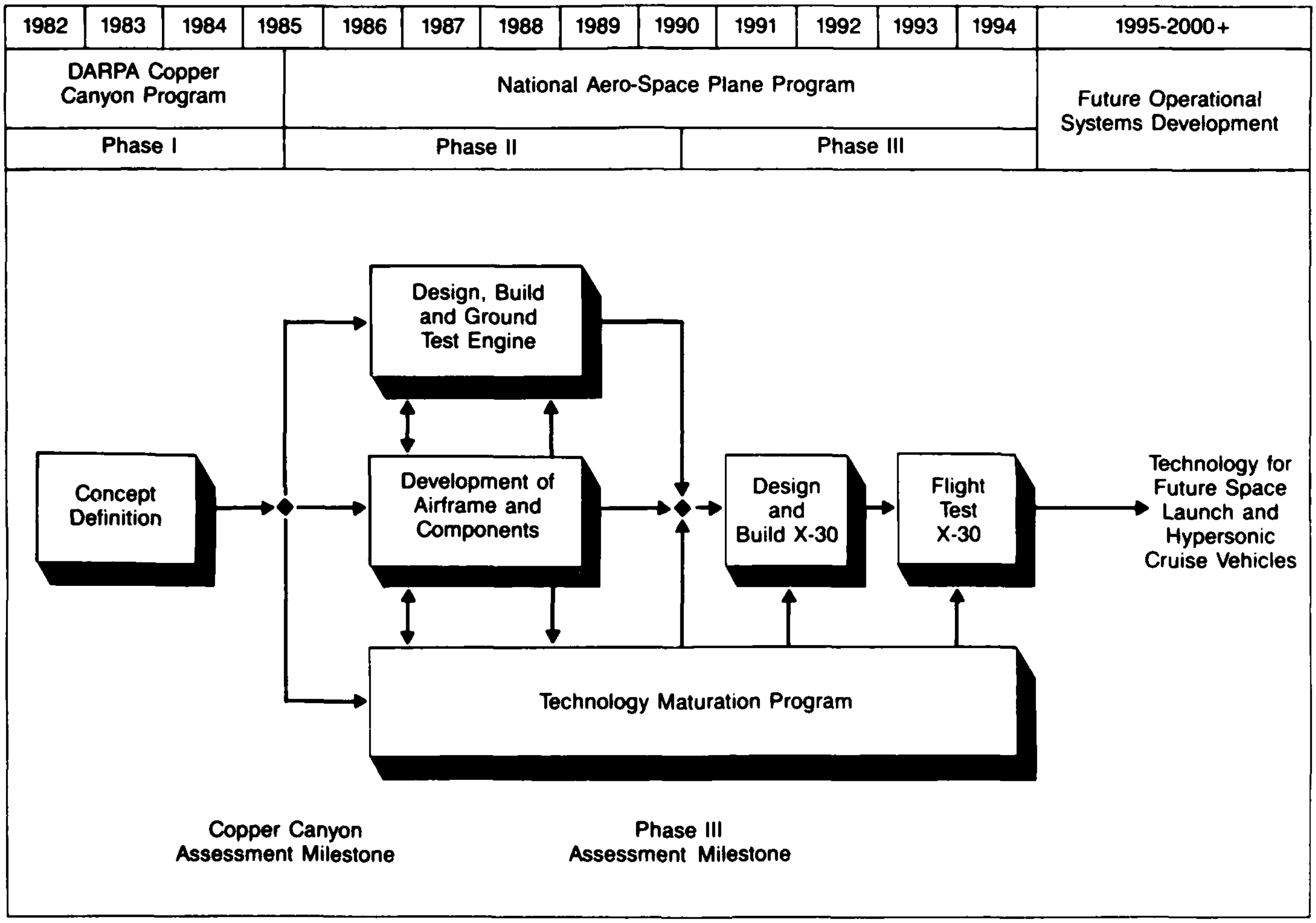
Confusion exists about what the X-30 is—and is not. The X-30 will be an experimental vehicle, not a prototype or operational vehicle. The X-30 will not carry any passengers or an operational payload. In fact, the X-30's payload will only consist of two crew members and test instrumentation. Also, the X-30 will not be a full-scale version of future operational aerospace vehicles.

The X-30 has no operational mission or requirements. As a technology development and demonstration program, the X-30 will be unconstrained by specific operational missions or user requirements. Future operational aerospace vehicles are not a part of the NASP Program, although they are likely to be an outgrowth of it.

What Is the NASP Program's Schedule?

Development of the X-30 will be accomplished in three phases as shown in figure 1.3.

Figure 1.3: National Aero-Space Plane Program Schedule and Milestones



Phase I (1982-85), code named "Copper Canyon," preceded the NASP Program, and its cost was approximately $5.5 million. Phase I was conducted by the Defense Advanced Research Projects Agency (DARPA) with technical expertise provided by the Air Force, the Navy, and NASA to define the technical concept of an aerospace plane, evaluate key technologies, and identify technical risks and approaches to reduce those

risks. It concluded that developing the aerospace plane and its enabling technologies was feasible with proper focus and management. As a result, the Secretary of Defense established the NASP Program in December 1985.

Phase II (1985-90) is a program of concept validation. It involves developing the necessary technologies for aerodynamics, the propulsion system, and airframe structures and materials. It also involves designing, validating, and ground testing key system components, such as the propulsion system and critical airframe component structures, and conducting utility and survivability assessments. Phase II is expected to cost about $0.9 billion between fiscal years 1986 and 1990.

At the end of Phase II, a decision will be made, based on the maturity of the technologies, on whether to build and test the X-30 experimental vehicle. Presently, no commitment exists to build the X-30.

If the decision is made to proceed, Phase III (1990-94) will involve building and testing three X-30 experimental vehicles: two for transatmospheric[6] flight testing and one for static ground testing. Flight testing of the X-30 is not scheduled to begin until 1994. This phase also continues the technology maturation process. Phase III is expected to cost about $2.4 billion between fiscal years 1990 and 1994.

On the basis of the results of the NASP Program, a decision could be made in the mid-1990s on developing future hypersonic cruise airplanes and single-stage-to-orbit space launch vehicles. If the NASP Program is successful, a prototype military, space, or commercial hypersonic airplane and/or single-stage-to-orbit space launch vehicle could possibly be built by the late 1990s.

Why Is the X-30 Being Developed Now?

The National Aero-Space Plane is being developed at this time because significant technological advances and even breakthroughs, based on actual test data, make the development of the X-30 potentially achievable. The following are examples of these advances and breakthroughs.

- Hypersonic combustion is now shown to be more efficient than earlier predicted.

[6]Transatmospheric refers to the flight of a vehicle at high Mach speeds through the earth's atmosphere and into orbit.

- New materials, such as rapid solidification technology (RST)[7] titanium-based alloys and metal matrix-composites, are being developed and integrated into new structural components that are extremely lightweight and high strength at high temperatures.
- Engine design can now be fully integrated with the airframe.
- New advances in computer programs and supercomputers can now accurately and quickly predict the fluid dynamics effects around model vehicles and within the scramjet.

Also, by the year 2000, space shuttle technology will be over 30 years old, and SR-71 strategic reconnaissance aircraft technology will be about 45 years old. During the first decade of the 21st century, the shuttle will reach—or be near—the end of its operational life. Thus, there is a need to look at future replacements. Given the long developmental cycle for a major new program (about 15 to 20 years, according to NASP Program officials), it is not too early to begin planning for the future.

Finally, according to NASP Program officials, the Soviet Union and other countries are also developing aerospace plane concepts and reusable space launch system technologies. These officials believe the military potential and technological payoffs are too great for the United States not to be a leader in developing aerospace vehicles.

How Much Will the X-30 Cost?

As shown in table 1.1, the NASP Program is expected to cost more than $3.3 billion between fiscal years 1986 and 1994. DOD plans to contribute about $2.7 billion, or approximately 80 percent, of the $3.3 billion total, while NASA plans to contribute about $675 million, or approximately 20 percent, of total program costs. This total does not include DARPA's Copper Canyon program, which cost about $5.5 million between fiscal years 1982 and 1985. It also does not include NASA's contributions in terms of personnel, facilities, and utility costs (estimated at about $500 million between fiscal years 1986 and 1994)[8] or industry's contribution (estimated at about $728 million between fiscal years 1986 and 1990).

[7]RST is a metallurgical process whereby molten alloys are transformed into a powder that is then consolidated or pressed into required shapes. The result is a lightweight alloy that is able to maintain high strength at high temperatures.

[8]NASA personnel, facility operations, and utility costs are not charged to the NASP Program, since these items are institutionally funded (appropriated by the Congress annually). In contrast, DOD civilian personnel, research facilities, and related costs are charged to the NASP Program, since use of DOD facilities is industrially funded (individual users, such as the NASP Program, are charged for their use). Costs for military personnel assigned to the NASP Program are charged to the military personnel account.

Table 1.1 shows NASP Program funding by DOD and NASA for fiscal years 1986-94.

Table 1.1: National Aero-Space Plane Program Funding by DOD and NASA by Fiscal Year

Dollars in millions

	Phase II					Phase III					
Agency	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**Unallocated[b]**	**Total**
DOD											
DARPA	$20	$100	$0	$0	$0	$0	$0	$0	$0	$0	$120
Air Force	10	0	183	245	400	500	495	396	159	123	2,511
Navy	6	0	0	0	0	0	0	0	0	0	6
SDIO[a]	9	10	0	0	0	0	0	0	0	0	19
Total	**45**	**110**	**183**	**245**	**400**	**500**	**495**	**396**	**159**	**123**	**2,656**
NASA	16	62	71	105	170	120	45	39	34	13	675
Total	**$61**	**$172**	**$254**	**$350**	**$570**	**$620**	**$540**	**$435**	**$193**	**$136**	**$3,331**

[a]Strategic Defense Initiative Organization.

[b]These unallocated amounts represent reductions in the fiscal year 1988 request and fiscal year 1989 budget proposal. These amounts will be included in the estimated expenditures for fiscal years 1990-94 DOD and NASA are currently determining which fiscal years will include the unallocated amounts

Initially, funding levels were identified for each DOD component between fiscal years 1986 and 1994.[9] However, in fiscal year 1987, the Congress directed that, beginning in fiscal year 1988, all DOD funding for the program be consolidated in the Air Force.

The growth from $172 million in fiscal year 1987 to $254 million in fiscal year 1988 reflects the fact that the NASP Program will begin to fabricate proof-of-concept propulsion systems (scramjet modules) for near full-scale ground testing up to Mach 8. It also reflects a continuing technology maturation effort to develop the critical enabling technologies.

Objectives, Scope, and Methodology

Our objectives were to describe the NASP Program and to provide a status of its technological developments. We focused on the National Aero-Space Plane's (1) goals and objectives, (2) program costs and schedule estimates, (3) key technological developments, integration, and risks, (4) potential military, space, and commercial mission applications, (5) program management and acquisition strategies, and (6) alternatives and

[9]Originally, DOD and NASA agreed that, during this period, DARPA would contribute $240 million, the Air Force $1.035 billion, the Navy $520 million, and SDIO $685 million for a total DOD contribution of $2.480 billion. DOD and NASA also agreed that NASA would contribute $597 million for a total program funding of $3.077 billion.

international aerospace plane development efforts. We did not address whether the NASP Program's enabling technologies will be sufficiently mature by 1990 to justify building and testing the X-30 experimental vehicle.

We conducted review work in Washington, D.C., at the NASP Program Management Office (PMO), DARPA, the Air Force, the Navy, SDIO, NASA, the Office of Science and Technology Policy in the Executive Office of the President, and the Department of Commerce. We also met with a member of the Defense Science Board.[10]

We also visited the NASP Joint Program Office (JPO) at Wright-Patterson Air Force Base in Dayton, Ohio; McDonnell Douglas in St. Louis, Missouri (an airframe contractor); Pratt & Whitney in West Palm Beach, Florida (a propulsion contractor); Aerojet TechSystems in Sacramento, California (a ground test contractor); NASA Ames Research Center at Moffett Field, California; and NASA Langley Research Center in Hampton, Virginia.

We received program and technical briefings, interviewed senior DOD, NASA, and contractor officials, engineers, and scientists, and conducted a literature search of international aerospace development efforts. At the contractor facilities, we visited supercomputer centers, RST powder metallurgy facilities, new materials development laboratories, hypersonic engine test facilities, and scramjet ground test facilities. At the two NASA research centers, we visited the Numerical Aerodynamic Simulator Cray 2 supercomputer facility and various subsonic, transonic, supersonic, and hypersonic wind tunnels, shock tunnels, and ballistic ranges.

We contacted or met with all of the other prime NASP airframe and propulsion system contractors to provide them an opportunity to comment on the NASP Program and their role in the program. These contractors included two propulsion contractors—General Electric and Rocketdyne—and four airframe contractors—Boeing, General Dynamics, Lockheed-California, and Rockwell International.

DOD, NASA, the Department of Commerce, and the Office of Science and Technology Policy in the Executive Office of the President commented

[10]The Defense Science Board is a senior independent advisory body to DOD. Currently, the Board consists of 36 members including 32 members-at-large who are selected on the basis of their preeminence in the fields of science and engineering. The Board, assisted by a group of senior consultants and other experts, undertakes studies referred to it by the Secretary of Defense, Under Secretary of Defense for Acquisition, or Chairman of the Joint Chiefs of Staff.

on a draft of this report and concurred with our findings. Technical and editorial comments by DOD and NASA, which were provided separately, and by the Office of Science and Technology Policy have been incorporated in the report, as appropriate. Agency comments appear in full in appendixes I through IV.

Our review was conducted between November 1986 and October 1987 in accordance with generally accepted government auditing standards.

What Is the NASP Program's Management Structure and Its Strategy to Reduce Risks?

The NASP Program is technologically challenging and a high-risk program. However, the potential payoffs are also high. According to NASP Program officials, the program's management strategy is designed to reduce some of the technological, programmatic, and financial risks associated with developing the X-30 experimental vehicle. Although the NASP Program's schedule and milestones may ultimately be achievable, they are ambitious and leave little room to accommodate potential design and integration problems or test failures that could delay the program and increase its costs. According to NASP Program officials, an increase in funding may reduce the technological risk and slippage in the program's schedule, but it may not speed up technology maturation or development. However, they also stated that a decrease in funding in any fiscal year may result in an extension of the program and ultimately increase its cost and technological risks.

Congressional concern has been expressed about NASA's perceived limited role in the program. NASA plans to contribute about 20 percent of overall program funding. However, in addition to NASA's funding contribution of $62 million in fiscal year 1987, NASA contributed about $70 million to the NASP Program in personnel, facility, and utility costs. NASA plans to contribute a similar amount in fiscal year 1988. It plays an integral role in the program and has the major role in technology maturation and lead responsibility for civilian aerospace technology applications. NASA's personnel and facilities are integrated into the NASP Program, and cooperation and coordination exist between NASA and DOD.

Industry has reported investing heavily thus far in the NASP Program—substantially more than the U.S. government—and has identified extensive investment in the program for the remainder of Phase II. NASP contractors, however, have expressed concerns about cost-sharing, sharing their proprietary data, and reporting proprietary NASP-related investments.

Why Is the NASP Program a Joint DOD/NASA Program?

The NASP Program was established as a joint DOD (Air Force, DARPA, Navy, and SDIO)/NASA technology development and demonstration program in December 1985. Based on the results of DARPA's Copper Canyon program, DOD and NASA concluded that the national interest, as well as their common objectives for developing an aerospace plane, would be best served by a joint program.

According to DOD and NASA officials, the NASP Program was also established as a joint DOD/NASA program because of the following reasons.

- Much of the required technical expertise and facilities are located throughout the United States in U.S. government departments, agencies, and laboratories; NASA research centers and facilities; industry; and universities. The program currently involves (1) DOD and NASA Headquarters, (2) NASA's Ames Research Center at Moffett Field, California; Langley Research Center in Hampton, Virginia; Lewis Research Center in Cleveland, Ohio; and Dryden Flight Research Facility at Edwards Air Force Base, California, (3) eight Air Force and eight Navy laboratories and centers, (4) the National Bureau of Standards, (5) two national laboratories, (6) 16 universities, and (7) 35 contractors.
- DOD and NASA officials wanted to consolidate and focus Air Force, Navy, DARPA, and NASA research and development in hypersonics and transatmospheric vehicles on the NASP Program.
- DOD and NASA recognized that the X-30's technologies would ultimately have military and civil mission applications and wanted to have potential follow-on aerospace plane users (the Air Force, the Navy, SDIO, and NASA) involved in the development of the X-30.

Organizational Concept and Responsibilities

The organizational concept of the NASP Program is that of a fully integrated, joint national program. A July 1986 Memorandum of Understanding between DOD and NASA formally assigned DOD responsibility for overall management of the NASP Program and NASA the major role for technology maturation and lead responsibility for civilian applications. It established the NASP Steering Group, committed agency resources (funds, personnel, and material), and affirmed the overall NASP Program objectives. DOD and NASA personnel are to participate jointly in all phases of the technology development, applications studies, and the design, fabrication, and flight testing of the X-30.

The Steering Group is responsible for providing policy, guidance, and broad programmatic direction for all phases of the NASP Program, but not for future programs directed toward operational systems development. The Steering Group is also responsible for resolving conflicts between the services and agencies concerning the NASP Program. Most importantly, the Steering Group will decide in 1990 whether to proceed to Phase III, subject to the consent of the Secretary of Defense and NASA Administrator. The Chairman of the Steering Group is the Under Secretary of Defense for Acquisition, and the Vice Chairman is the Associate Administrator of NASA's Office of Aeronautics and Space Technology. Each participating agency is represented in the Steering Group.

An April 1986 internal DOD Memorandum of Agreement defined the responsibilities of the DOD participants in the program—the Air Force, DARPA, the Navy, and SDIO. It assigned the Air Force overall DOD responsibility; established the management structure; committed Air Force, DARPA, Navy, and SDIO resources; and established NASP Program objectives.

DARPA is responsible for managing the Phase II (1985-90) technology development effort,[11] including preparing the Phase II program management plan and the technology readiness assessment. This assessment, which will include a proposed X-30 design, is expected to be presented to the NASP Steering Group at the flight vehicle decision milestone in 1990.

The NASP PMO was established in DARPA in January 1986. It consists of a DARPA Program Manager and Program Directors representing the Air Force, the Navy, and NASA. SDIO is represented by the Air Force Program Director. The PMO is responsible for overall management and coordination of Phase II and reports to the Director of DARPA.

To carry out its responsibilities as the Executive Agency for DARPA, the Air Force established the NASP JPO in January 1986. The JPO implements the technical program and manages the contracts. It reports directly to the PMO. The JPO has an Air Force Program Manager and Air Force, Navy, and NASA Deputy Program Managers. It also has an integrated staff of Air Force, Navy, and NASA military and civilian personnel. SDIO is represented by the Air Force Deputy Program Manager. The JPO serves as the Executive Agency for the PMO during Phase II and is scheduled to become the Executive Agency for the Air Force during Phase III.

Each service or agency provides resources to support the NASP Program. All program funding, regardless of source, is assigned to the JPO. The PMO, however, controls and allocates funding to five program areas: (1) airframe contractors, (2) propulsion system contractors, (3) the technology maturation program, (4) program support, and (5) operational utility studies.

[11] According to NASP Program officials, DARPA was the logical choice to manage the day-to-day operations for Phase II, since DARPA had conducted the Phase I Copper Canyon Program.

How Is the NASP Program's Management Strategy Designed to Reduce Technological, Programmatic, and Financial Risks?

The NASP Program is technologically challenging and a high-risk program. The program is dependent upon the successful development and integration of several critical or enabling technologies, each of which requires significant technological advances or breakthroughs. The program, therefore, faces substantial technological, programmatic, and financial risks.

Technological Risks

According to NASP Program officials, NASA scientists, and NASP propulsion and airframe contractors, the greatest technological risk to the viability of an aerospace plane is the development of an air-breathing propulsion system. The greatest technological challenge is achieving enough thrust and propulsion efficiency over the entire speed range to power the X-30, given the weight of the vehicle.

Other technological risks include developing advanced materials that are high strength, lightweight, able to withstand high temperatures, and fully reusable; integrating the X-30's basic systems (propulsion, airframe, thermal control, structures, and avionics); and relying heavily on computational fluid dynamics to predict the aerodynamic, thermal, and propulsion characteristics at the critical high-Mach number end of the flight spectrum (Mach 8 to 25) due to the lack of adequate ground test facilities. These technological risks are discussed in more detail in chapter 3.

Programmatic Risks

Due to high technological risks of immature technology, the NASP Program may face difficulty in meeting its schedule. The NASP Program is ambitious in that its goal is to design, fabricate, and flight test the X-30 by the end of fiscal year 1994. Historically, one of the principal causes of schedule delays in experimental programs is unexpected technical problems or failures.

Financial Risks

The NASP Program also faces financial risks from cuts in program funding as the Congress weighs the relative priority of the NASP Program with other programs given budgetary constraints. Industry also faces substantial financial risks. Airframe and propulsion contractors have reported substantial investment of research, capital, and personnel

resources in the NASP Program. One airframe contractor told us that airframe contractors have been asked to absorb both technical and financial risks for developing an experimental vehicle. A propulsion contractor noted that NASP contracts are firm fixed-price contracts that provide for no fee, no margin, and no reserve. Contractors told us they face financial risks if program funding is cut or if they are not selected as a result of the engine or aircraft concept or design reviews. The NASP Program's acquisition strategy and efforts to incorporate industry investment into acquisition plans are discussed later in this chapter.

NASP Program Management Strategy to Reduce Risks

NASP Program officials have developed a management strategy that they believe will reduce some technological, programmatic, and financial risks through mechanisms built into the strategy. These include the following:

- Use of existing national assets (both government and industry-owned) whenever possible to reduce programmatic risks by using facilities such as wind tunnels and laboratories to minimize delays in the NASP schedule caused by construction of new facilities and to reduce operational costs significantly.
- Multiple technical approaches to reduce not only technological risks by increasing the likelihood of finding a solution, but also programmatic risks by finding solutions sooner than by using only one approach.
- Competition among industry to reduce technological risks by providing different contractor concepts.
- Use of firm fixed-price contracts to minimize the government's financial risks.
- A technology maturation program parallel to the engine and airframe development program to reduce risks in all three categories by promoting competition and providing alternatives. U.S. government activities in this program include over 125 projects to address the enabling technologies. The technology maturation program, according to NASP Program officials, increases the likelihood of finding solutions quicker and at less cost.
- Engine and airframe concept and design reviews and decision points at established program milestones to reduce risks in all three categories by making sure the contractors have developed adequate concepts and designs and by setting specific program milestones, thus controlling costs.

Are the NASP Program's Schedule and Milestones Realistic and Achievable?

The NASP Program's goal to design, fabricate, and flight test the X-30 by the end of fiscal year 1994 is ambitious. Although its schedule and milestones may ultimately be achievable, they leave little room for design and integration problems or test failures that could delay the program. If any of the enabling technologies does not mature as quickly as expected, the entire program could be delayed, and its costs could be increased.

One propulsion contractor described the NASP Program schedule as challenging and tough, but not unachievable. Another propulsion contractor told us that the NASP timetable may be somewhat optimistic and that feedback of experimental results into the X-30's design is quite limited by the schedule.

An airframe contractor told us that the milestones leading to the 1990 decision on whether to proceed to Phase III are "aggressive and carry considerable risk." Another airframe contractor noted that the JPO had established ambitious goals that forced all of the contractors to accelerate their technical understanding of air-breathing aspects of a vehicle that is expected to reach speeds over Mach 20. He added that it would be difficult to predict whether all program goals can be achieved or which goals must be achieved to label the program a success. According to a senior NASP Program official, if a decision is made in 1990 not to proceed with Phase III, then Phase II would be extended to allow the technologies to mature so that the program, although delayed, could continue. Again, a decision would have to be made whether to proceed with Phase III.

Design and integration problems are common in an experimental program when new technologies must not only be developed but be fully integrated as well; the design of one component affects the performance of another component. The Director of JPO noted that there are risks and that there probably will be disappointments, setbacks, and even failures.

What Is the Impact of Potential Funding Changes on Cost and Schedule Estimates?

DOD and NASA officials believe the NASP Program's current funding level is appropriate. According to NASP Program officials, although an increase in funding may reduce the technological risk and slippage in the program's schedule, it may not speed up technology maturation or development. However, a decrease in funding in any fiscal year could result in an extension of the program, which could ultimately cost more and increase technological risks.

DOD and NASA officials also believe that NASP Program costs would significantly increase if the schedule were either slowed down or speeded up. Slowing down the program could result in increased costs due to inflation, an extension of the schedule, and the possibility that contractors may lose interest in the program and limit or discontinue their investment. Speeding up the schedule would add more risks, which could require more funding to manage those risks.

A 4-month slippage of the NASP Program's schedule occurred in fiscal year 1987. According to JPO officials, this was caused by (1) a reduction of $44 million in the fiscal year 1987 appropriations request and (2) what they describe as "only moderate design progress." According to these officials, the evaluation of contractors' initial designs by a NASP team took longer than expected. Also, airframe contractors required more time to assemble their teams, since many of the contractors lacked adequate experience in hypersonics. These officials view the extension as a risk-reduction decision and the lowest cost method for extending the propulsion and airframe contracts.

The effect of the slippage was a (1) 4-month extension of Phase II milestones, (2) $2.4 million increase in each of the five airframe contracts, and (3) $13 million increase in each of the propulsion contracts.

A 6-month extension in the NASP Program's schedule is expected in fiscal year 1988. According to NASP Program officials, this would be caused by (1) reductions in fiscal year 1988 appropriations and (2) additional time to incorporate contractors' component test results in their engine and airframe designs. This 6-month extension has been approved on an interim basis by the Director of DARPA, pending approval by the NASP Steering Group.

Congressional Concern Over NASA's Role in the NASP Program

Congressional concern has been expressed about (1) NASA's perceived limited role in the NASP Program and the need for a major civilian component and (2) insufficient NASA contribution to the program's research, development, test and evaluation costs.

NASA's Perceived Limited Role and Need for a Civilian Component

Although NASA's overall direct funding contribution to the NASP Program only totals about 20 percent ($675 million out of a total program cost of more than $3.3 billion), senior NASA Headquarter and NASP Program officials do not believe that DOD is dominating the NASP Program or its decision-making process. According to a senior NASA official, all principals in the program understand that the program is a joint DOD/NASA program. NASA's responsibilities are stated in the Memorandum of Understanding between DOD and NASA. Within the NASP Program, NASA has the major role in technology maturation and has been assigned lead responsibility for civilian applications. NASA plays an integral role in the overall program. Its personnel participate in all phases of technology development, application studies, and the design, fabrication, and flight testing of experimental flight vehicles.

The Associate Administrator of NASA's Office of Aeronautics and Space Technology serves as the NASP Steering Group's Vice Chairman. Moreover, NASA is represented in the PMO by a Program Director who reviews any proposed major changes in the technology development objectives or allocation of resources in Phase II. Similarly, NASA is represented in the JPO by a Deputy Program Manager who is responsible for planning and designing X-30 missions unique to NASA as well as monitoring NASA funds and resources. This official also has administrative responsibility for NASA personnel assigned to the JPO. Again, any proposed major changes in Phase II objectives or schedule affecting allocation of NASA resources require review by the NASA Deputy Program Manager.

Overall, NASA's role is defined, and its personnel and facilities are integrated into the NASP Program. Cooperation and coordination exist between NASA and the other participating agencies.

NASA's Funding

The Department of Defense Appropriations Act for fiscal year 1987 (P.L. 99-500) restricted obligation of one-half of DOD's fiscal year 1987 NASP appropriation of $110 million until the Secretary of Defense certified that (1) NASA had agreed to assume a significantly larger portion of NASP research, development, test and evaluation costs than its current 20 percent contribution and (2) industry investment out of private capital had been incorporated into the NASP Program's acquisition strategy. The Secretary of Defense and NASA Administrator revised NASA's funding profile, increasing NASA's share of the research, development, test and evaluation portion of the NASP Program (Phase II) by about 40 percent from 20.2 to 28.2 percent of the revised total Phase II costs between fiscal years 1986 and 1990.

The Secretary of Defense certified to the Congress in March 1987 that NASA's investment as a percentage of total Phase II costs had significantly been increased. The new funding profile was incorporated in the Revised Memorandum of Understanding between DOD and NASA.

Even though NASA increased its investment as a percentage of total Phase II costs, the Congress inserted similar language to the fiscal year 1987 legislation in the Department of Defense Appropriations Act for fiscal year 1988 (P.L. 100-202). This legislation restricts obligation or expenditure of one-half of DOD's fiscal year 1988 appropriation of $183 million until the Secretary of Defense certifies that DOD and NASA have negotiated revised funding arrangements for NASP development which significantly increase NASA investment as a percentage of total NASP research, development, test and evaluation costs.

In addition to NASA's fiscal year 1988 contribution of $71 million as shown in table 1.1 (see p. 19), NASA plans to contribute $70 million to the program—$25 million in personnel costs and $45 million in facility operations and utility costs—during fiscal year 1988.

NASA currently has about 300 scientists and engineers dedicated to the NASP Program. NASA is also using its three research centers to carry out the technology maturation program and plans to use its Dryden Flight Research Facility to conduct flight tests of the X-30 during Phase III.

A significant number of tests are planned using NASA's supersonic and hypersonic wind tunnels and simulators, as well as extensive use of NASA's computational facilities, primarily the Cray 2 supercomputer, which is part of NASA's Numerical Aerodynamic Simulator facility. Currently, the NASP Program is using up to one-half of the time available on the Cray 2 supercomputer. According to the Director of the Numerical Aerodynamic Simulator facility, no application uses computational fluid dynamics more than the NASP Program. The Director told us that use of the Cray 2 supercomputer by the NASP Program is expected to increase greatly during fiscal year 1988.

NASA's Dryden Flight Research Facility is expected to play a major role in conducting flight tests of the X-30 experimental vehicle beginning in 1994. Dryden will be involved in developing flight systems, avionic controls, air data systems and sensors, and flight path and flight pattern simulations. This facility is also expected to test heat and load conditions of various structural components for the X-30.

NASP Program Acquisition Strategy and Incorporating Industry Investment Into Acquisition Plans

As part of the program's acquisition strategy, the NASP Program awarded multiple firm fixed-price contracts to (1) take advantage of competition, which reduces technological risks and provides alternatives, (2) require corporate investment, and (3) limit U.S. government liability. In April 1986, the NASP Program awarded two propulsion and five airframe firm fixed-price contracts that could potentially total $510.9 million. Propulsion contracts were awarded to General Electric (potentially totaling $176.1 million) and Pratt & Whitney (potentially totaling $172.3 million).[12] Airframe contracts were awarded to Boeing, General Dynamics, Lockheed-California, McDonnell Douglas, and Rockwell International for a potential total of $32.5 million each. Each of the contracts contain options for future work based on the results of the engine and airframe concept reviews.

This strategy also included conducting engine and airframe concept reviews to ensure that the prime contractors had developed adequate engine and airframe concept designs. As a result of the Engine Concept Review in August 1987, the number of propulsion contractors was reduced from three to two. Pratt & Whitney and Rocketdyne were selected to proceed to the next phase. The Aircraft Concept Review in October 1987 resulted in the number of airframe contractors being reduced from five to three. General Dynamics, McDonnell Douglas, and Rockwell International were selected to proceed to the next phase.

NASP Program officials did not want the prime contractors to team up before the engine and airframe concept reviews to maintain competition. After those decision points, NASP officials are not opposed to contractors teaming up to conduct preliminary design work. However, NASP Program officials said that they will review any proposed teaming carefully to ensure that program acquisition strategies and policies are met before approving such teaming.

Industry Investment

Despite substantial risks, industry has reported investing heavily in the NASP Program in anticipation of receiving potentially high payoffs. Industry has reported investing about $353 million in the NASP Program during fiscal years 1986 and 1987 compared with the U.S. government's expenditure of about $233 million appropriated for the NASP Program during that same period. According to NASP Program contractors, these

[12] Rocketdyne did not bid on the propulsion contract, but decided later to participate in the NASP Program using its own funding. Rocketdyne was granted access to the program and generic data that is shared with all contractors. Rocketdyne's results are shared with the U.S. government.

investments include such items as ground and engine test facilities, supercomputers, supersonic wind tunnels, and RST facilities. Some of these investments may also be used by other programs. Moreover, according to NASP Program officials, industry plans to invest about $145 million in fiscal year 1988, about $167 million during fiscal year 1989, and about $63 million during fiscal year 1990. NASP Program contractors expressed concerns about cost-sharing, sharing their proprietary data, and reporting proprietary NASP-related investments.

Cost-Sharing

NASP contractors are concerned about cost-sharing with no near-term product or payoff. For example, one airframe contractor told us that fixed-price contracting is inappropriate, given the technological risks. Another airframe contractor stated that officials of the company do not believe the NASP Program is providing sufficient resources to resolve many critical airframe risk areas, and, as a consequence, airframe contractors are facing substantial funding shortfalls and/or prospects for unprecedented levels of contract investment.

Data Rights

The U.S. government has full data rights during Phase II to share basic technological data and information with all participating contractors. During Phase III, NASP contractors will be permitted to retain all data rights to their proprietary design concepts. However, NASP contractors are concerned about sharing their proprietary data during Phase II with both the U.S. government and, in turn, with their competitors. According to one NASP contractor, if its company is not selected to continue after a review milestone, then its proprietary data and design concepts have essentially been given away.

Reporting Proprietary NASP-Related Investments

To meet the requirement of Public Law 99-500 that the Secretary of Defense certify that industry investment out of private capital had been incorporated into the NASP Program's acquisition plans, the JPO established contractor reporting requirements. These requirements include a one-time contractor investment report due 1 week before the Engine Concept Review or Airframe Concept Review and a quarterly report thereafter of actual and planned corporate investment in the program by fiscal year.

The quarterly report is intended to identify actual and planned investments from (1) profits, (2) capital expenditures (facilities and new equipment), and (3) new business development (funds from independent

research and development and other funds that develop generic technologies that are applicable to NASP). Contractors may not invest independent research and development funds from a NASP contract back into the NASP Program. These funds may, however, be invested in programs unrelated to the NASP Program.

According to NASP Program officials and contractor representatives, no other U.S. government program requires a similar report of corporate investment in a program. NASP contractors are concerned that their competition will find out their corporate strategy in terms of actual and planned investment in the NASP Program.

The Secretary of Defense certified to the Congress in March 1987 that industry investment out of private capital had been incorporated into the NASP Program's acquisition plans. The Secretary of Defense also authorized the Assistant Secretary of Defense (Comptroller) to release the restricted $55 million in NASP Program funds for obligation.

Conclusions

The need to successfully develop and integrate several enabling technologies make the NASP Program technologically challenging and a high-risk program. However, the program also has potentially high payoffs. The program is a fully integrated joint program that, according to NASP Program officials, is designed to reduce some technological, programmatic, and financial risks.

Although the program's schedule and milestones to design, fabricate, and flight test the X-30 by the end of fiscal year 1994 may ultimately be achievable, they are ambitious. The program could be delayed and its costs increased by potential design and integration problems or test failures. According to NASP Program officials, although an increase in funding may reduce technological risk and slippage in the program's schedule, it may not speed up technology maturation or development. However, they also stated that decrease in funding in any fiscal year may result in an extension of the program, which could increase its cost and technological risks.

NASA's personnel and facilities are integrated into the NASP Program, and cooperation and coordination exist between NASA and DOD. NASA has the major role for technology maturation and lead responsibility for civilian applications in Phase II.

Industry has reported making significant investment in the NASP Program thus far—substantially more than appropriated for the NASP Program—and has identified extensive investment for the remainder of Phase II. NASP contractors are concerned about (1) cost-sharing with no near-term product or payoff, (2) sharing their proprietary design concepts with the U.S. government and other contractors, and (3) reporting current and projected proprietary NASP-related investments.

Can the NASP Program Develop Enabling Technologies Sufficiently to Justify Building and Testing the X-30?

Significant technological advances and even breakthroughs have occurred in technologies critical to the NASP Program that make developing and demonstrating the X-30 possible. However, each of the enabling technologies must be developed further and fully integrated with the others, since the design of one component can have a large impact on the performance of another component.

Adequate ground test facilities to test components of the X-30 above speeds of Mach 8 for sustained periods do not exist. Thus, the X-30 is being developed as a "flying test bed" to validate the enabling technologies and computational fluid dynamic flight simulations at speeds between Mach 8 and 25.

The X-30 is being developed as a manned vehicle to provide more flexibility and system control than an unmanned automated system. According to NASP Program officials, a manned vehicle also provides invaluable human input in analyzing and evaluating complex aspects of experimental flight. Flight testing of the X-30 will involve new risks, since no vehicle has attempted to expand the operational limits of current air-breathing aircraft by 10-fold. Safety features in key systems are being incorporated in the X-30's design.

What Are the X-30's Enabling Technologies and Why Are They Critical?

Failure to successfully develop and demonstrate any of the enabling technologies could adversely affect the NASP Program. The success of the NASP Program also depends on the integration of those technologies in the X-30 experimental vehicle.

Even if the NASP Program does not achieve its primary objective of developing an X-30 that will demonstrate single-stage-to-orbit space launch capability, other key objectives such as hypersonic cruise capability, maturation of key technologies, and technological spin-off applications may still be achievable.

Propulsion System: Air-Breathing Supersonic Combustion Ramjet

The NASP Program's most critical enabling technology is the propulsion system. A propulsion system must be developed with sufficient thrust and efficiency to power the X-30 over its full range of speed from take-off to Mach 25. A supersonic combustion ramjet (scramjet) is being developed, since the atmospheric flight envelope (speed and altitude) in which the X-30 must operate is 10 times greater than the technical limits of current air-breathing engines. A hydrogen-fueled scramjet is

believed to be the only air-breathing engine that can operate at speeds of up to Mach 25.

A ramjet is the primary propulsion system for aircraft operating at supersonic speeds of about Mach 2 to 5.5. A ramjet compresses or "rams" the onrushing air and slows it down to subsonic speeds where it is burned with the fuel in a combustion chamber. A ramjet cannot gather enough air to work efficiently at subsonic speeds, and it becomes inefficient again above Mach 5.5, since energy is lost in slowing down the air flow to subsonic speeds in the combustion chamber.

A scramjet is designed to operate at speeds of about Mach 4 and faster, although no upper limit has yet been found. Model scramjets have been tested in wind tunnels up to speeds of Mach 8 and in shock tunnels up to speeds of Mach 20, but never during actual flight. Supercomputers using computational fluid dynamics have simulated scramjet flights up to speeds of Mach 32. Orbital escape velocity, at which speed the X-30 would enter orbit, is Mach 25.

The scramjet is created from a ramjet configuration by adjusting the position of air inlet panels, internal struts, and exhaust panels. As air flows through the combustion chamber at supersonic speeds, gaseous hydrogen is injected into the combustion chamber. The hydrogen is ignited by the hot air, and the exhaust (primarily water vapor) is expelled through the nozzle, causing the thrust. Only gaseous hydrogen can be used in a scramjet, since it is the only fuel that will ignite at such high speeds.

The propulsion system must operate over a range of speeds from takeoff up to Mach 25. Various propulsion concepts will be integrated to provide the most efficient air-breathing propulsion system over this speed range. These concepts include a number of low-speed propulsion options that could be used to accelerate the X-30 from takeoff up to speeds of about Mach 3. Ramjets could then be used between speeds of Mach 3 and 6. Next, scramjets could take over between speeds of Mach 6 and 25. Rocket propulsion may be used during the X-30's final ascent into orbit. Rocket propulsion will also be necessary for maneuvering in orbit and for deorbiting.

Propulsion contractors have conducted studies over a range of operating conditions, developed engine design configurations, and selected an approach for developing a propulsion system. Propulsion contractors

are currently conducting preliminary scramjet test module design analysis, scramjet component tests, and sub-scale scramjet tests. This effort is scheduled to end in a Test Module Review in late 1988. After that, the contractors will refine their propulsion system design and build and test a near full-scale engine module. This phase is scheduled to end in late 1989.

The technological challenge is to achieve sufficient thrust and efficiency in the engine throughout its speed range. According to PMO officials, analysis of conceptual engine designs indicates that a propulsion system for the X-30 that meets all of the program's goals can be built. However, developing the necessary materials to build the engine and demonstrating predicted engine efficiencies and component performance must also be achieved.

Advanced Materials

The second most critical enabling technology is that of advanced materials. To minimize the fuel and thrust required by the engine, the weight of the X-30 must be reduced as much as possible. Also, hypersonic flight causes extremely high temperatures due to air resistance on the vehicle's surfaces and within the scramjet. For example, the X-30's nose cone could reach more than 5,000 degrees Fahrenheit, and the leading edges of the wing and tail could reach almost 3,500 degrees Fahrenheit. Therefore, materials must be developed that are not only high strength and lightweight but also able to withstand extremely high temperatures and be reusable.

Advanced materials include carbon-carbon,[13] titanium-based alloys, fiber composites, and RST-produced ti-aluminide (titanium-aluminum). According to NASP Program officials, most of the X-30 will be built using RST powder metallurgy. RST is a process in which molten titanium and aluminum are transformed into a very fine powder, which is then solidified. The resulting alloy (ti-aluminide) demonstrates much higher strength and stiffness at high temperatures compared to conventional titanium alloys. Moreover, it has one-half the weight of the material previously used at these high temperatures.

Currently, one propulsion and one airframe contractor are building larger RST facilities to manufacture production-level quantities of ti-

[13] Carbon-carbon is a material that consists of 100 percent carbon fibers in a carbon matrix. The material does not contain any binders or epoxy. It is coated with a ceramic material. Carbon-carbon is extremely lightweight and is being considered for use on the X-30's wing and tail control surfaces.

aluminide. The technological challenge they face is to develop and produce large quantities of high strength and lightweight materials that are able to withstand high temperatures and are fully reusable. Also, component fabrication and joining technology are being developed for advanced materials.

Thermal Control Technologies

The X-30 will also require thermal control technologies to control tremendous heat loads. Since most metals cannot maintain their structural integrity above 1,800 degrees Fahrenheit, some components of the X-30 (such as the nose cone, wing and tail leading edges, and the inside walls of the engine's combustion chamber) will have to be actively cooled, even though they will be made of advanced heat-resistant materials.

A heat pipe cooling system is being considered for cooling the nose cone and leading edges. This technology is useful in components where the temperature between one area and an adjacent area differ widely (such as between the nose cone and fuselage or wing edge and wing surface). Heat is transferred by the evaporation of a fluid in heat pipes located in the leading edge structure and is then transported to cooler areas of the structure. The result is a heat transfer system that is capable of transporting and dissipating vast amounts of heat over large areas such as a wing or the fuselage.

Supercooled liquid hydrogen fuel may also be used as a coolant to actively cool the cockpit, airframe structural components, and scramjet before it is used as a fuel. Engine performance is increased by using hydrogen that is already hot as it is injected into the engine's combustion chamber. Thus, the engine is able to achieve higher thrust and efficiency than if cold hydrogen were used.

Platelet technology is also being considered for use in a thermal control system. Very small and intricate passages for transporting a cooling fluid through a hot component can be made by constructing the component from a series of very thin sheets of the desired material. Each sheet is photoetched to create the holes or passages desired. The sheets are then placed on top of one another and fused together. Even though this technology is over 20 years old, better materials and the improved ability to create very thin passages in thin structures hold considerable promise for use with new materials in the X-30. Another advantage of this technique, particularly for development and experimental work, is that the designs can easily be modified, and a new part can be made very quickly.

Currently, NASA's research centers and NASP contractors are developing the heat pipe cooling technology and use of supercooled hydrogen as a coolant to actively cool the X-30's hot airframe and engine structures. A ground test contractor is perfecting its platelet technology for use in a thermal control system.

Engine/Airframe Integration

The X-30 is being designed with an integrated engine and airframe. Scramjet performance is dependent upon the flow of air entering the engine, which is affected by the shape of the X-30's forebody. Moreover, much of the engine's thrust is obtained after the exhaust leaves the engine by pressures the exhaust creates on the X-30's afterbody. Thu , the design of the engine and airframe must be closely integrated, since each will affect the other's performance.

The entire underside of the X-30's forebody will serve as the air inlet to compress the air for the engine. Similarly, the underside of the X-30's afterbody will serve as the engine's exhaust nozzle. This area acts as an expansion surface similar to the shuttle's main engine bell-shaped exhaust nozzle.

Much of the initial design work on an integrated engine/airframe has been completed. However, propulsion and airframe contractors will have to work closely together to design and test an integrated engine and airframe.

Computational Fluid Dynamics and Supercomputers

Computational fluid dynamics—the use of advanced computer programs to solve a set of mathematical equations with a high-speed digital computer—is extensively used in the NASP Program to simulate air flows, high temperatures, and pressure contours around various design configurations of an aerospace plane and within the scramjet at high-Mach speeds. These calculations are used in the design of the X-30's engine and airframe.

Computational fluid dynamics is also used to simulate the X-30's performance between speeds of Mach 8 and 25 where ground test facilities or capabilities do not exist and actual test data are not available. Computational fluid dynamic computer programs must also be validated by actual test data at lower speeds, which are then compared to the theoretical calculations. Modifications to the programs are then made where appropriate. These programs are also used by the PMO to test and verify contractors' work.

Advances in supercomputers over the past several years have allowed extensive use of computational fluid dynamics in the NASP Program. Eight supercomputers like the Cray 2—the world's fastest and most powerful computer—are now being used in the NASP Program to perform millions of complex calculations in the design and simulation of the X-30's performance. According to NASA officials, use of supercomputers has resulted in more accurate and faster air flow calculations. For example, the Cray 2 can perform 250 million continuous calculations per second, more than three times faster that the previous generation of supercomputers. Nonetheless, each pressure contour calculation takes 3 hours on the Cray 2.

Each prime contractor has also acquired a supercomputer. However, some said they probably would not have made that capital investment had it not been for the NASP Program.

The critical areas where computational fluid dynamics and supercomputers are used include calculating the air flows (1) around the forebody and engine inlets, (2) inside the engine's combustion chamber (the most difficult set of calculations), (3) around the afterbody and nozzle area (which involves many experimental calculations), and (4) around the entire integrated engine/airframe. The NASP Program needs to develop computational fluid dynamic computer programs further before they are used by the contractors. A major effort in the technology maturation program involves improving, expanding, and calibrating these computer programs against experimental data to make the programs more usable as design tools. According to a JPO official, several years may be required to develop adequate production programs.

The technological challenge facing the NASP Program is to provide computational fluid dynamic computer programs that can accurately calculate performance for flight conditions beyond ground test capabilities, make the programs usable by the contractors through documentation of test results and training, and develop program modifications to meet specific NASP Program needs.

Efficient Use of Hydrogen

The efficient use of hydrogen both as a fuel and a coolant to actively cool components could result in (1) a fuel that can ignite quickly in the supersonic airflow inside the engine's combustion chamber and provide high energy per unit volume and (2) additional space for a larger payload by eliminating the need to carry a separate cooling agent. Much

of the internal space of the X-30 will consist of a supercooled hydrogen fuel tank.

Both liquid and slush hydrogen[14] are being considered for use as a fuel, but each presents a different set of problems. Liquid hydrogen reacts with some metals, causing them to become brittle, which weakens the metals. Research under the technology maturation plan is being conducted to find new materials or coatings to eliminate this problem. Slush hydrogen needs to be maintained in a uniform mixture and requires special pumps and plumbing to handle it. However, since slush hydrogen is more dense than liquid hydrogen, more fuel—and thus more energy—can be carried in a given volume of the fuel tank.

What Supporting Technologies Are Required for the X-30?

Although not critical, supporting technologies are important in the development and demonstration of the X-30. Many supporting technologies (such as advanced avionics, artificial intelligence, and life-support systems) were advanced during the manned space program and most recently during the shuttle program.

For example, advanced avionics are being designed for use in the X-30's flight control systems. An automated system is planned for vehicle and system checkout and turnaround on the ground, during hypersonic cruise, or while in orbit. This system could also help reduce operational costs by minimizing ground crew size.

Although the development of new advanced avionics systems is not a major part of the NASP Program, participating U.S. government laboratories and contractors are conducting research programs in this area for other applications. The results are being applied to the X-30. Development is proceeding on a vehicle management system, data processing system, quadruple back-up flight control system, and design of the crew station. The X-30's navigation system is expected to use a global positioning system, which is a worldwide navigation system using satellites.

The technological challenge in avionics is to achieve (1) integration of the flight, propulsion, and thermal control systems, (2) precise trajectory control given vehicle and atmospheric uncertainties, and (3) simultaneous control over performance, stability, and the flight path.

[14]Slush hydrogen is a mixture of liquid and frozen hydrogen and is denser than liquid hydrogen.

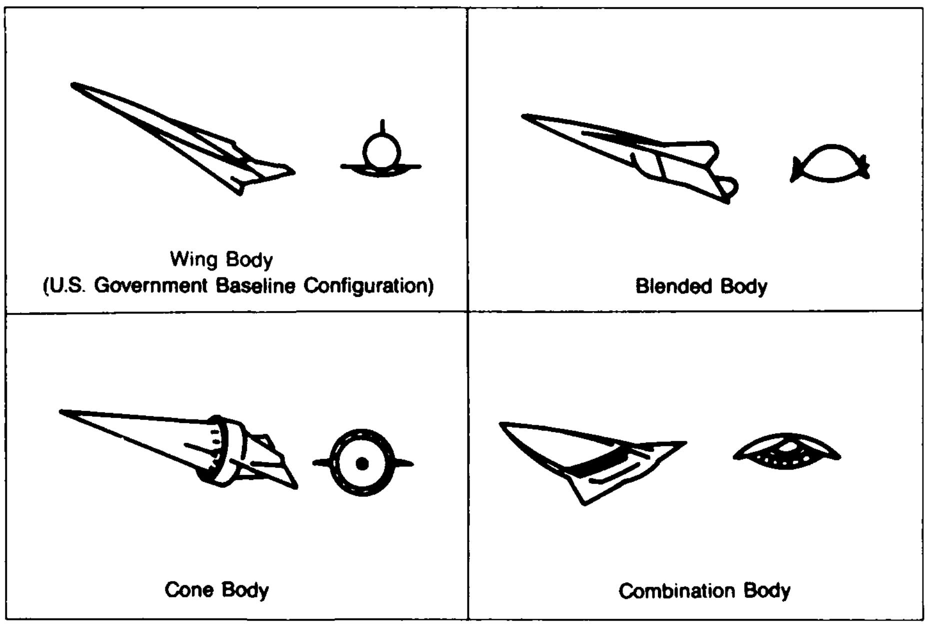
Why Is Technological Integration Important?

The X-30's basic systems—aerodynamics (lift, drag, and control movements), thermal control (active cooling and external coatings), propulsion system (air inlet, combustor, and exhaust nozzle), and structures (fuel tank, wings, tail, and materials)—must be fully integrated with each other to develop the X-30 successfully. According to NASP Program officials, the X-30 will be one of the first vehicles requiring almost total system integration.

Advantages and Disadvantages of Various Design Configurations

As discussed in chapter 1, the air flow around the X-30's forebody affects the engine's performance as the design of the afterbody affects the engine's thrust and the aircraft's stability and control. The need to fully integrate the X-30's engine and airframe led to four generic designs as shown figure 3.1. These designs are used in aerodynamic wind tunnel and computational fluid dynamic testing. In addition, they serve as the basis for contractors to develop their own proprietary designs and to measure the performance of their designs over the original configuration.

Figure 3.1: X-30 Experimental Vehicle Generic Design Configurations



The wing body concept—the U.S. government's baseline design configuration—has a rounded fuselage and an engine that is integrated underneath the body. This configuration is aerodynamically efficient, allows

for a large fuel tank, and provides good vehicle control at low speeds. Its disadvantage is the difficulty in integrating the exhaust nozzle with the airframe's afterbody.

The blended body configuration is elliptically shaped with an engine integrated underneath the body. This design has light structural weight and good thermal protection. Its disadvantages over the wing body configuration are its reduced aerodynamic efficiency and reduced low speed control.

The cone body configuration has a rounded body and engine integrated around the entire body. Its major advantages include its thrust and large fuel tank. Its major disadvantages over the wing body design are its reduced aerodynamic efficiency and reduced stability and control.

The combination body configuration has a turtle-shaped body with rounded scramjet integrated underneath the body. This configuration is efficient aerodynamically; its disadvantages over the wing body design are its higher structural weight and the need for added thermal protection.

Programmatic Integration

Just as the enabling technologies must be integrated to achieve the technical goals of the NASP Program, its management structure must also be integrated to achieve the programmatic goals, schedule, and milestones. NASA and industry have reportedly assigned their best scientists, engineers, and specialists to the NASP Program to achieve the technological advances required and to maintain U.S. aeronautical leadership. The necessity for design integration has forced many of these persons to interact more often with their peers in other fields. The large amount of communication, coordination, and interaction required, while time consuming, has generated a great deal of support for the program.

Why Limitations in Ground Test Capabilities Require an Experimental Vehicle

Adequate ground test capabilities and facilities to test the X-30 above speeds of Mach 8 for sustained periods do not exist. In fact, no single facility or group of facilities are capable of creating the combination of velocities, temperatures, and pressures necessary to simulate the X-30's actual flight conditions. Therefore, the X-30 is being developed as a "flying test bed" to validate the requisite technologies at speeds between Mach 8 and 25.[15]

Ground test facilities (such as wind tunnels, shock tunnels, ballistic ranges, and engine test stands) are used to conduct various tests of X-30 models and components. Ground tests establish a database and validate computational fluid dynamic simulations.

Ground tests tend to be of short duration. For example, hypersonic wind tunnel tests generally last from only microseconds[16] up to a few seconds. Not enough energy can be produced to run wind tunnel tests for a long time. Thus, energy must be stored and blasted through the wind tunnel all at once.

Ground test facilities have very limited capability and productivity and are expensive to build. For example, wind tunnels and shock tunnels can only measure the effects of a change in one variable (such as velocity, temperature, or pressure) at a time. Since only one or two tests can be run each day in a wind tunnel, productivity is low. The cost savings of using existing facilities are significant. According to a JPO official, the cost of building a new shock tunnel, for example, could total hundreds of millions of dollars.

The NASP Program plans to use existing ground test facilities to the maximum extent possible. Also, $9.6 million is being spent to upgrade and modify two existing engine test facilities, and many of NASA's long-dormant hypersonic wind tunnels and shock tunnels are being reactivated; others are being refurbished and upgraded specifically for the NASP Program. The program plans to use computational fluid dynamics simulation to fill in the gaps in X-30 test capability.

[15] In a similar situation, the North American X-15 research aircraft, which flew 199 times up to speeds of Mach 6.7 between 1959 and 1968, was not fully tested until its first flight. The X-15 was built of new materials to explore flight conditions that were not precisely defined and for which incomplete aerodynamic information was available.

[16] A microsecond is one-millionth of a second.

According to the Office of Science and Technology Policy, four complementary techniques are desirable for testing at speeds between Mach 8 and 25. These techniques include (1) laboratory experiments and use of ground test facilities such as wind tunnels, (2) use of advanced computational modeling, prediction, and extrapolation, (3) instrumented flight tests by the shuttle, missiles, and other space launch vehicles, and (4) actual flight tests of the X-30 experimental vehicle as it explores the flight regime.

Engine Test Facility

After determining that existing Air Force, NASA, industry, and university engine test facilities were not capable of testing scramjets above speeds of Mach 8 for sustained periods and were not suitable for testing contractor's engine test modules, the NASP Program awarded two contracts in October 1986 totaling $9.6 million for two Engine Test Facilities. These facilities are expected to provide the capability to test full-scale scramjets up to speeds of Mach 8.

Operating engine test facilities also entails risks. Heating facilities that generate extremely high temperatures are required to achieve high-Mach numbers. These facilities are very volatile and are hazardous to operate. Consequently, two engine test facilities are being upgraded and modified so that if one is damaged, the other facility can be used to avoid program delays.

To validate enabling technologies by the 1990 decision milestone, the NASP Program plans to (1) develop better test techniques (such as improvements in instrumentation, flowfield simulation techniques, and using computational fluid dynamics to extend test capabilities), (2) upgrade and modify existing ground test facilities, (3) actively pursue additional capabilities (such as reactivating, upgrading, and modifying other existing facilities or building new facilities), and (4) consider using existing ground test facilities in, for example, the United Kingdom and Australia.

Why Is the X-30 Being Developed as a Manned Vehicle?

The X-30 is being developed as a manned vehicle to achieve more flexibility and system control than an automated system would. These are particularly important during takeoff and landing. According to NASP Program officials,

- in an experimental research vehicle, input by a human pilot is invaluable when analyzing and evaluating such complex aspects of flight as stability and control as well as propulsion control with multiple engines;
- a piloted vehicle would be more valuable than an unmanned vehicle in validating the X-30's handling and transition from one speed regime to another; and
- an automated control system for an unmanned X-30 would require an extensive command, control, and communication network, including ground links and satellites, since the X-30's flight range requirements could initially cover much of the continental United States, and such an automated control system would increase program costs and extend its schedule.

Incorporating Safety Features Into the X-30's Design

Flight testing of the X-30 experimental vehicle, which is expected to proceed in a step-by-step process, will involve new risks because no vehicle has ever attempted to expand the flight envelope for air-breathing aircraft by 10-fold and to demonstrate so many new technologies. Thus, safety features are being incorporated into the X-30's design. These include

- a multi-engine propulsion system;
- use of hydrogen as a fuel, resulting in less danger of fire compared with conventional fuels, since its ignition temperature in air is 1,065 degrees Fahrenheit or twice that of aviation grade kerosene;
- a flight control system that has four backup systems;
- a flight trajectory that is above severe weather conditions;
- the ability to make a powered landing and maneuvering capability if a landing had to be aborted; and
- test instrumentation and monitoring systems for the engine and airframe structure.

Foreign Object Damage

Foreign object damage from small rocks on a runway, birds, hail, ice, rain, or even space debris could cause severe damage to the X-30. The two most vulnerable areas are the engine components and the vehicle's skin. Foreign object damage to the nose cone or leading edges could

cause structural damage, since those areas experience extremely high temperatures and must be actively cooled.

Scramjet designs have inherent strength against particle damage, since they do not have fragile internal components (such as turbines) like conventional turbojet engines. The use of multiple engine modules also reduces the risk of catastrophic damage due to foreign objects.

The X-30's skin, particularly on the underside of the vehicle, is expected to be constructed of honeycomb material that has inherent protection against impacts. Finally, the X-30's ascent trajectory avoids hypersonic cruise flight through regions where ice clouds may be present.

Conclusions

The NASP Program is a high-risk program with potentially high payoffs. Substantial technological progress and breakthroughs have been achieved in the propulsion system, advanced materials, computational fluid dynamics, and integration of the engine and the airframe. Analysis of conceptual engine designs indicates that a propulsion system for the X-30 that meets all of the program's goals can be built. However, developing the necessary materials to build the engine and demonstrating predicted engine efficiencies and component performance must also be achieved.

Even if the NASP Program does not achieve its primary objective of developing an X-30 that will demonstrate single-stage-to-orbit space launch capability, other key objectives may still be achieved. These include hypersonic cruise capability, maturation of key technologies, and technological spin-off applications.

Ground test capabilities are limited. No group of facilities can adequately test all of the parameters (velocity, temperature, and pressure) above Mach 8 for sustained periods. Thus, the X-30 must serve as a "flying test bed" to validate the technologies and test those conditions between Mach 8 and 25.

Chapter 4

What Are the Potential Uses and Alternatives for an Operational Aerospace Plane?

Future operational aerospace planes will be based on the technology developed and demonstrated by the NASP Program. As discussed in chapter 1, the X-30 is being designed to demonstrate both hypersonic cruise and single-stage-to-orbit space launch capabilities. If the program can validate the requisite technologies, future military, space, and commercial hypersonic cruise airplanes and single-stage-to-orbit space launch vehicles could be developed in the 21st century. Specific missions and firm operational requirements for future aerospace vehicles probably will not be identified by potential users until the X-30's capabilities have been demonstrated.

Although future operational single-stage-to-orbit space launch and hypersonic cruise vehicles may have technical, cost, and operational advantages over existing systems, these capabilities may not be required for some missions. Thus, existing or planned subsonic or supersonic aircraft and space launch vehicles may be more cost-effective than an operational aerospace plane for some missions.

National aeronautical research and development goals of maintaining and extending U.S. aeronautical leadership and preeminence into the 21st century are being challenged by foreign countries' development of technologies for operational aerospace planes. To secure independent access to space and to reduce the costs of launching payloads into orbit, the British, French, West Germans, Soviets, and Japanese are each developing technologies for their own concept of an aerospace plane. According to officials of the Office of Science and Technology Policy and the Department of Commerce, political, economic, financial, technological, and legal reasons make international cooperation in developing the X-30 undesirable.

What Are the Potential Military, Space, and Commercial Mission Applications?

The X-30 has no operational mission or requirements. As a technology development and demonstration program, the NASP Program is unconstrained by specific user requirements. However, based on the capabilities to be demonstrated by the X-30, potential users (such as the Air Force, the Navy, SDIO, NASA, and commercial aviation) will identify specific missions and firm operational requirements.

A decision by DOD and NASA is expected in the mid-1990s on developing two new classes of aerospace vehicles: hypersonic cruise airplanes and single-stage-to-orbit space launch vehicles. On the basis of the results of the NASP Program and if a decision is made to develop future aerospace vehicles, a prototype of an operational vehicle could possibly be built by

the late 1990s. However, a prototype vehicle would not likely resemble the X-30 experimental vehicle. The X-30 will be designed to demonstrate both hypersonic cruise and single-stage-to-orbit space launch capabilities; a prototype or operational vehicle probably would only perfect one capability, since it is unclear that an operational need exists for a vehicle with both capabilities. An operational military aerospace plane would probably be developed first followed by an operational commercial aerospace plane 10 to 15 years later.

Even though future operational systems development is not a part of the NASP Program, NASP JPO officials told us that they began identifying potential mission applications in March 1987. However, these officials also told us that it is premature to develop specific applications until the program achieves sufficient engine performance given the weight of the vehicle. About 1 percent of the NASP Program's total funding for the Phase II technology development effort ($8 million out of $837 million between fiscal years 1986 and 1990) is allocated to identify mission applications for future operational aerospace planes.

Potential Military Mission Applications

A hypersonic cruise airplane with sustained cruise capability between speeds of Mach 5 and 14 could have significant military applications, including a

- hypersonic airplane to carry out interdiction, reconnaissance, surveillance, and precision targeting and weapons guidance missions;
- hypersonic bomber for strategic bombing operations; and
- hypersonic transport for strategic airlift missions.

According to NASP Program officials, an aerospace plane deployed at just six bases around the world (on the east and west coasts of the United States, in Alaska, on Guam, and on the British possessions of Diego Garcia in the Indian Ocean and Ascension Island in the South Atlantic Ocean) could deploy anywhere in the world in 45 minutes or less and be within no more than a 4,000-nautical mile range of a recovery base. This capability is not possible with current aircraft.

A single-stage-to-orbit space launch vehicle could also have important Air Force and Navy mission applications such as

- high-altitude reconnaissance and
- deploying, servicing, repairing, and retrieving communications, surveillance, navigation, warning, and weather satellites in low earth orbit.

SDIO is interested in a single-stage-to-orbit space launch vehicle to reduce the costs of launching payloads into orbit. However, it may be too late to develop such a vehicle for the proposed first increment in deployment of a Strategic Defense System. Moreover, heavy launch boosters may be needed for deploying large components.

Potential Space Mission Applications

A single-stage-to-orbit aerospace plane using air-breathing propulsion could significantly reduce the cost of launching a payload into orbit compared with the shuttle and other projected space launch systems. It could also provide the United States with on-demand access to space and alternative means of launching payloads into orbit. Potential NASA mission applications include

- ferrying astronauts and supplies to and from the proposed space station;
- launching, repairing, and retrieving satellites and other vehicles in low earth orbit; and
- serving as a space rescue vehicle.

Although an operational aerospace plane would not be developed in time to launch space station components into orbit as currently scheduled, it could service the proposed space station. Finally, an aerospace plane could be a follow-on vehicle to the shuttle as it nears the end of its operational life during the first decade of the 21st century.

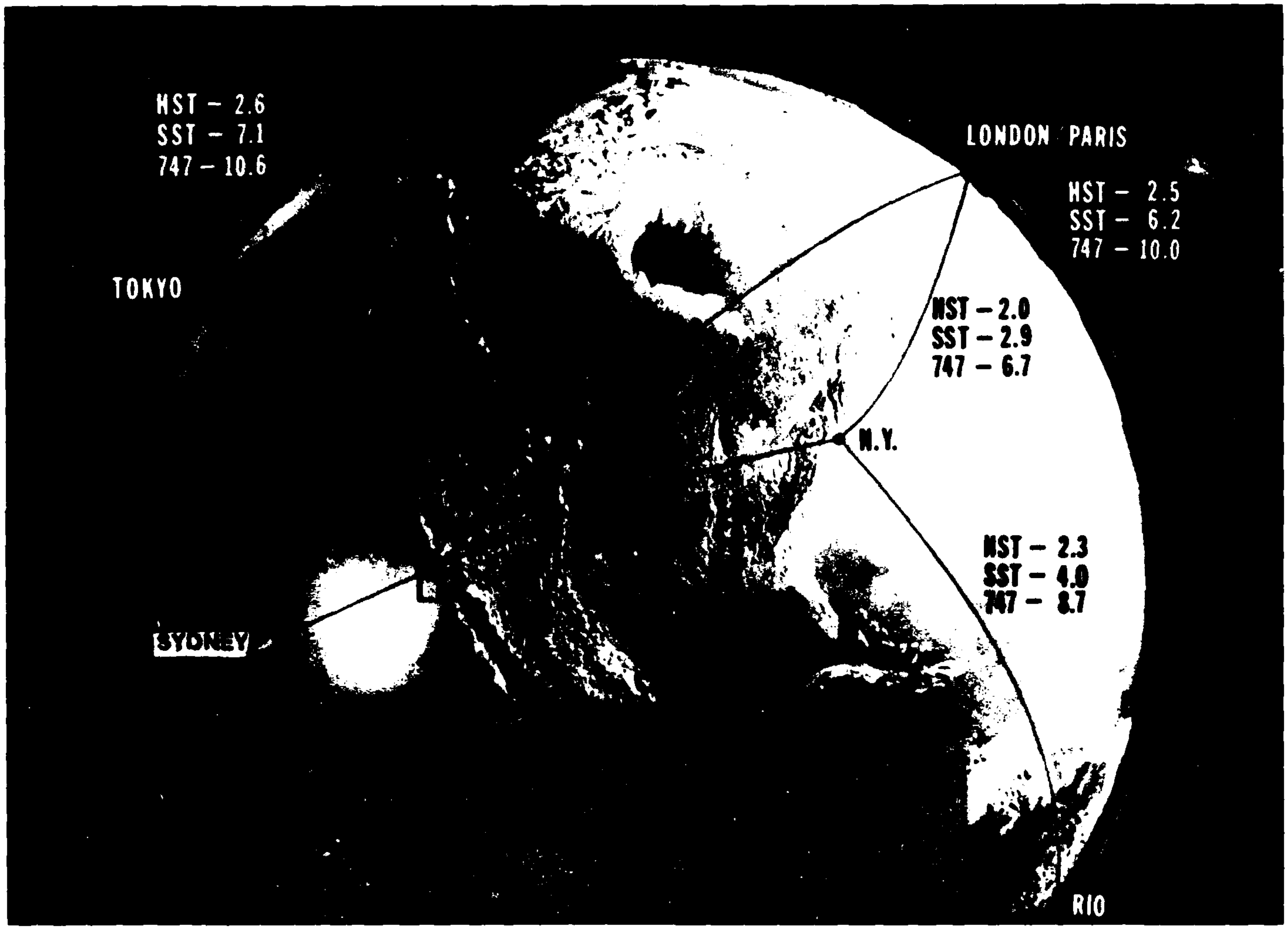
Potential Commercial Mission Applications

Sustained hypersonic cruise capability within the atmosphere would dramatically shorten the time required for long-haul passenger and cargo air routes. Figure 4.1 compares the transit time between selected destinations for current subsonic aircraft, a supersonic transport, and a future hypersonic transport.

For example, the time required for flying non-stop between Los Angeles, California, and Sydney, Australia, would be 13.5 hours for a Boeing 747 flying at a speed of Mach 0.7 (about 550 mph); 4.9 hours for the supersonic Concorde cruising at a speed of Mach 2 (about 1,400 mph); and 2.5 hours for a hypersonic transport cruising at a speed of Mach 6 (about 4,500 mph). A hypersonic transport would allow more round-trip flights per day.

Apart from the NASP Program, NASA has been working with industry to examine civil market opportunities, identify the most promising aircraft

Figure 4.1: Comparison of Travel Time Between Selected Destinations for Subsonic, Supersonic, and Hypersonic Transport Aircraft (In Hours)



Source NASA

design concepts and cruise speeds, and define additional technological requirements for both advanced supersonic and hypersonic transport aircraft.

Could Supersonic Transport Environmental Concerns Inhibit Development of a Hypersonic Transport?

Environmental concerns that inhibited the development of the supersonic transport in the late 1960s and early 1970s, such as the sonic boom and depletion of the ozone layer, are not likely to be as significant a problem in the development of a hypersonic transport. The sonic boom of a hypersonic transport would be reduced due to higher flight altitudes and thinner air, and a hypersonic transport is not expected to cruise in that region of the atmosphere where its exhaust could adversely affect the ozone layer. Both factors were major reasons why the United States discontinued its supersonic transport program in 1971.

Ground overpressure or the sonic boom is created by the airplane's shockwaves during supersonic flight. Because the flight altitude of a hypersonic transport would probably be 100,000 feet or above compared with 60,000 to 70,000 feet for a supersonic transport, the overpressure intensity at ground level is reduced due to thinner air and greater distance from the ground. A hypersonic transport's sonic boom is expected to be about one-third that of the Concorde. Whether this lower pressure level is sufficient to permit flights at hypersonic speed over land has not been fully determined.

The other environmental concern that affected development of the supersonic transport was the adverse effect of its exhaust on the earth's protective ozone layer. At the supersonic transport's cruising altitude of about 65,000 feet, its exhaust would adversely affect the ozone layer. In comparison, a hypersonic transport is not expected to cruise in that region of the atmosphere where the ozone layer could be affected by its exhaust. In addition, a hypersonic transport's exhaust consists primarily of water vapor, which will likely have little or no effect on the ozone layer.

What Are the Alternatives to an Operational Aerospace Plane?

Although future hypersonic flight vehicles may have technical, cost, and operational advantages over existing systems, hypersonic speed may not be required for some missions. Thus, existing or planned aircraft may be more cost-effective than an operational aerospace plane for those missions.

Furthermore, the proposed shuttle follow-on vehicle may be an alternative to future single-stage-to-orbit space launch vehicles for some missions. Unmanned rocket boosters may also provide alternatives to an aerospace plane particularly for unmanned missions and for launching

heavy payloads into orbit. A major goal of U.S. space policy is a diversified space launch capability. Thus, existing and planned unmanned rocket boosters may complement an aerospace plane.

Alternatives to a commercial hypersonic transport include supersonic transports, which do not require technological advances or breakthroughs that an operational aerospace plane requires or ground support facilities to handle liquid hydrogen fuel. However, supersonic aircraft may have greater adverse environmental effects such as the sonic boom and depletion of the ozone layer. According to NASA, both supersonic and hypersonic aircraft must meet environmental capability requirements in terms of noise and emissions, and these issues are currently being studied by NASA.

Finally, other countries are also exploring or developing reusable aerospace vehicles that offer alternatives to U.S. aerospace planes. These include the British Horizontal Takeoff and Landing (HOTOL) vehicle, French Hermes Spaceplane, German Sanger II Advanced European Space Transportation System, Soviet Aerospace Plane and Hypersonic Transport, and Japanese H-II Orbiting Plane (HOPE) and future spaceplane.

What Is the Status of International Aerospace Plane Development Efforts?

National aeronautical research and development goals of maintaining and extending U.S. aeronautical leadership and preeminence into the 21st century are being challenged by foreign countries' development of operational aerospace plane technologies. The United Kingdom, France, West Germany, the Soviet Union, and Japan are each developing technologies for various concepts of aerospace planes to secure independent access to space and to reduce costs of launching payloads into orbit. The proposed designs for the British HOTOL, French Hermes, German Sanger II, Soviet Hypersonic Transport, and the Japanese HOPE aerospace vehicles are illustrated in figures 4.2 through 4.6.

British HOTOL Vehicle

The British HOTOL vehicle is being designed as an unmanned single-stage-to-orbit, fully recoverable, and reusable space launch vehicle. HOTOL is designed to carry a single payload of about 8 tons into low earth orbit and will be launched by a rocket-powered wheeled-trolley or sled from a conventional runway. HOTOL will be powered by an air-breathing engine that will use liquid hydrogen at low speeds and that would convert to a rocket engine at Mach 5 in the upper atmosphere to boost the vehicle

Figure 4.2: British HOTOL Vehicle

Source: GAO

into orbit. It would glide back to earth and land horizontally on a conventional runway. HOTOL is expected to be about the size of the Concorde.

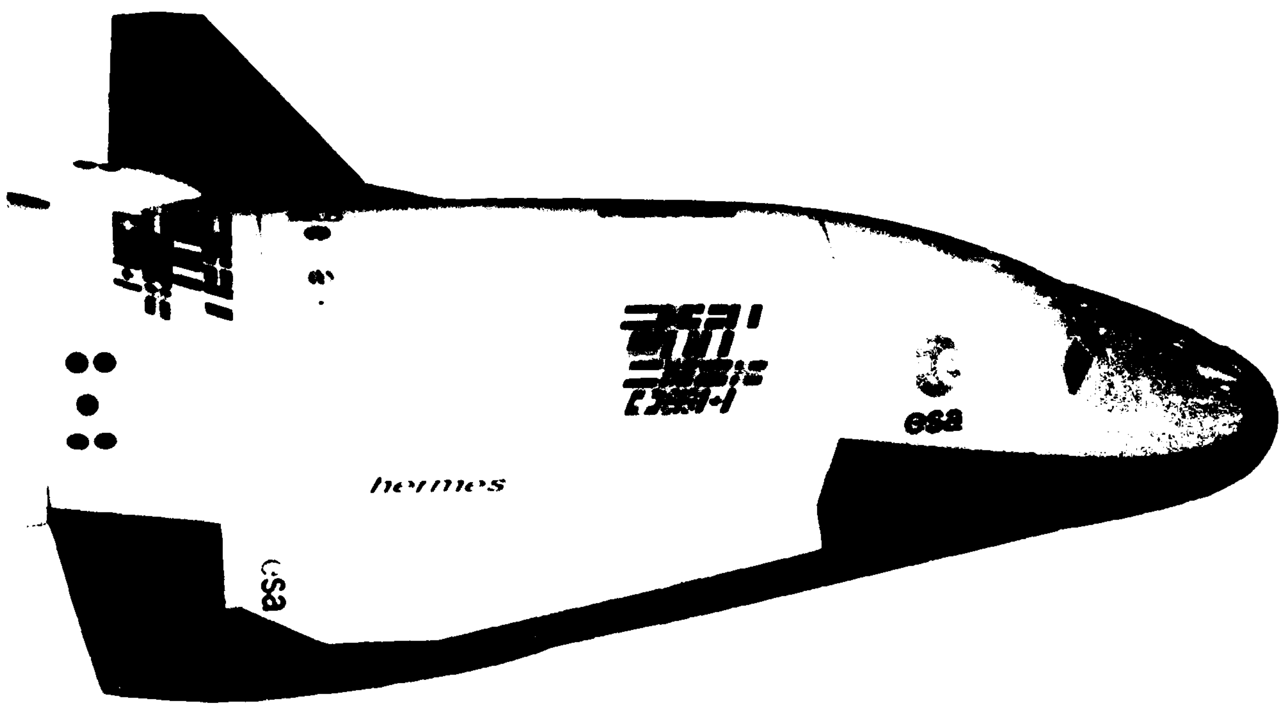
The primary objective of HOTOL is to reduce launch costs by a factor of at least five compared with the shuttle. Its primary role will be to launch satellites or transfer cargo to the European Space Agency's Columbus module attached to the proposed U.S. space station. Manned operations could be achieved by placing a passenger capsule in the payload bay. If fully supported, an unmanned version of HOTOL could become operational in 1997 and a manned version in the year 2000.

French Hermes Spaceplane

The French Hermes Spaceplane is being developed as a manned reusable shuttle-like reentry winged vehicle. Hermes would be launched by the Ariane 5 rocket booster, also under development, from the European Space Agency's Kourou Space Center in French Guiana. Hermes would return to earth and land horizontally on a conventional runway. In space, Hermes would be powered by rocket engines.

Hermes' primary mission would be to provide space transportation for astronauts and supplies to the Columbus module of the planned U.S. space station. It is being designed to carry a crew of three and a cargo payload of about 3 tons into low earth orbit. The French spaceplane is

Figure 4.3: French Hermes Spaceplane



Source GAO

not designed to launch satellites. That role would continue to be performed by the Ariane launcher. Typical missions are expected to last 11 days, but could last up to 28 days. In addition, Hermes could support both American and Soviet space stations as well as other satellites and space platforms, conduct in-orbit experiments, and carry out space rescue missions. Hermes would also be fitted with an ejectable crew cabin.

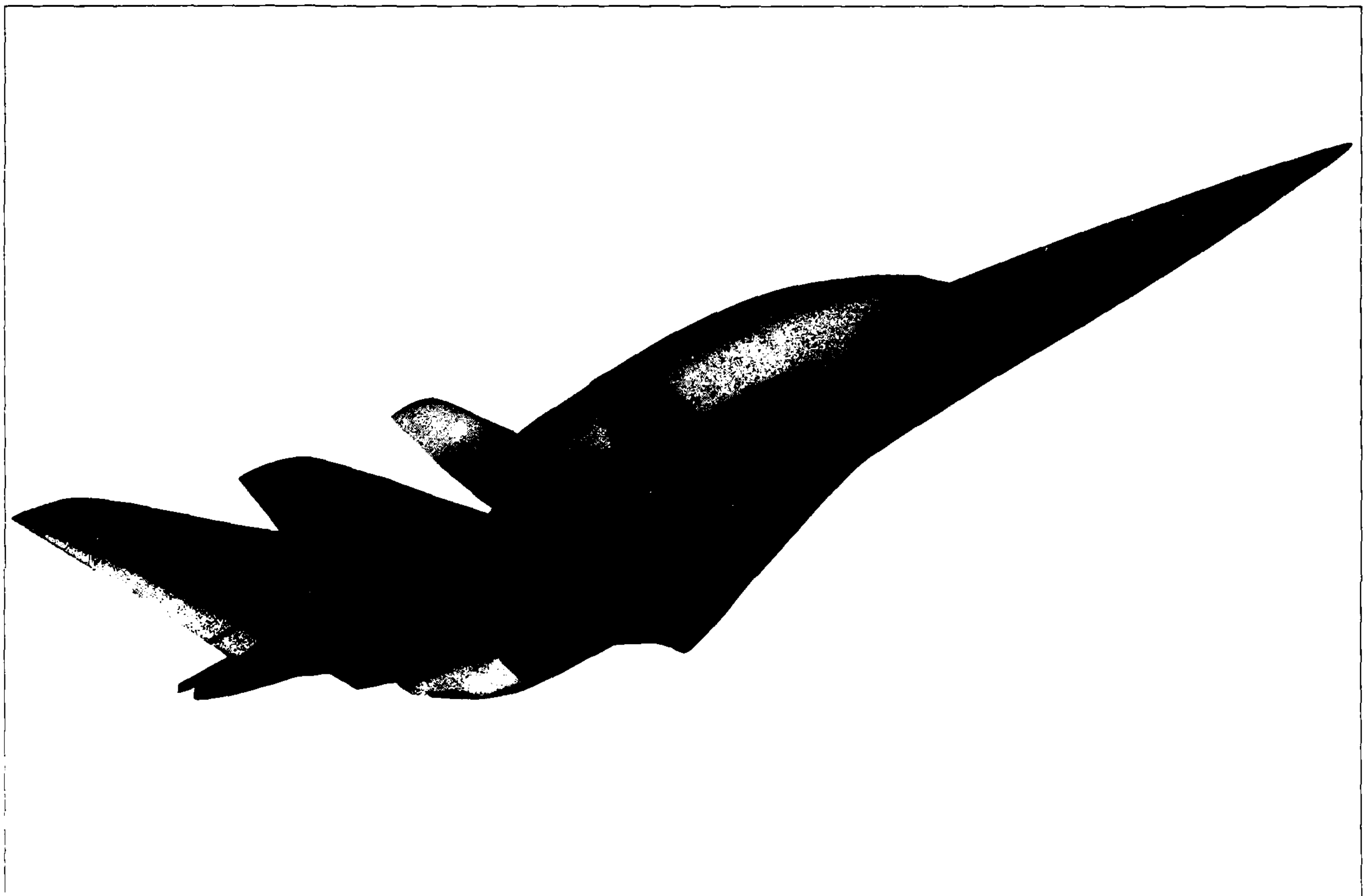
The Hermes development program is being conducted by the European Space Agency. Hermes is expected to become operational in 1999.

German Sanger II Advanced European Space Transportation System

Sanger II is conceived as being a two-stage space launch vehicle capable of horizontal takeoff and landing from European airports. The first stage is expected to be an air-breathing hypersonic aircraft powered by a turboramjet using liquid hydrogen and to provide the technological basis for a future European hypersonic passenger aircraft. The second stage would consist of either a manned or unmanned vehicle. The manned second stage, known as Hypersonic Orbital Upper Stage (HORUS), would be a reusable reentry winged vehicle powered by rocket engines and would carry two to four crew members, four passengers, and a small payload of 2 to 4 tons into low earth orbit. HORUS would serve as a transportation vehicle (typically spending 1 day in orbit) for manned space operations, space station support, and eventually space tourism. The unmanned second stage, known as Cargo Upper Stage (CARGUS), would be an expendable cargo transport also powered by rocket engines that would launch payloads up to 15 tons into low earth orbit or 2.5 tons into geostationary orbit. CARGUS is also expected to launch heavy payloads for lunar and planetary missions. Sanger II with HORUS is expected to be about the size of a Boeing 747 airplane.

Sanger II is being developed primarily to reduce launch costs to about 20 percent of the French Ariane 5 rocket booster with Hermes and to provide Europe with an independent access to space and autonomy in launching the vehicle horizontally from European airports. Sanger II is considered as a logical follow-on to the French Hermes Spaceplane and is expected to use existing technology. According to German officials, the earliest operational date for Sanger II is 2005.

Figure 4.4: German Sanger II Advanced European Space Transportation System



Source American Institute of Aeronautics and Astronautics

Soviet Aerospace Plane and Hypersonic Transport

Although some doubts exist as to whether the Soviets are actually developing an aerospace plane, they have reportedly conducted flight tests of sub-scale experimental aerospace vehicles. The Soviets exhibited a model of a hypersonic cruise airplane at the Paris Air Show in June 1987. A full-scale version of a Soviet aerospace plane is expected to take off horizontally from a conventional runway using rocket engines, climb into the upper atmosphere or attain low earth orbit, and return to land horizontally on a runway.

Figure 4.5: Soviet Hypersonic Transport

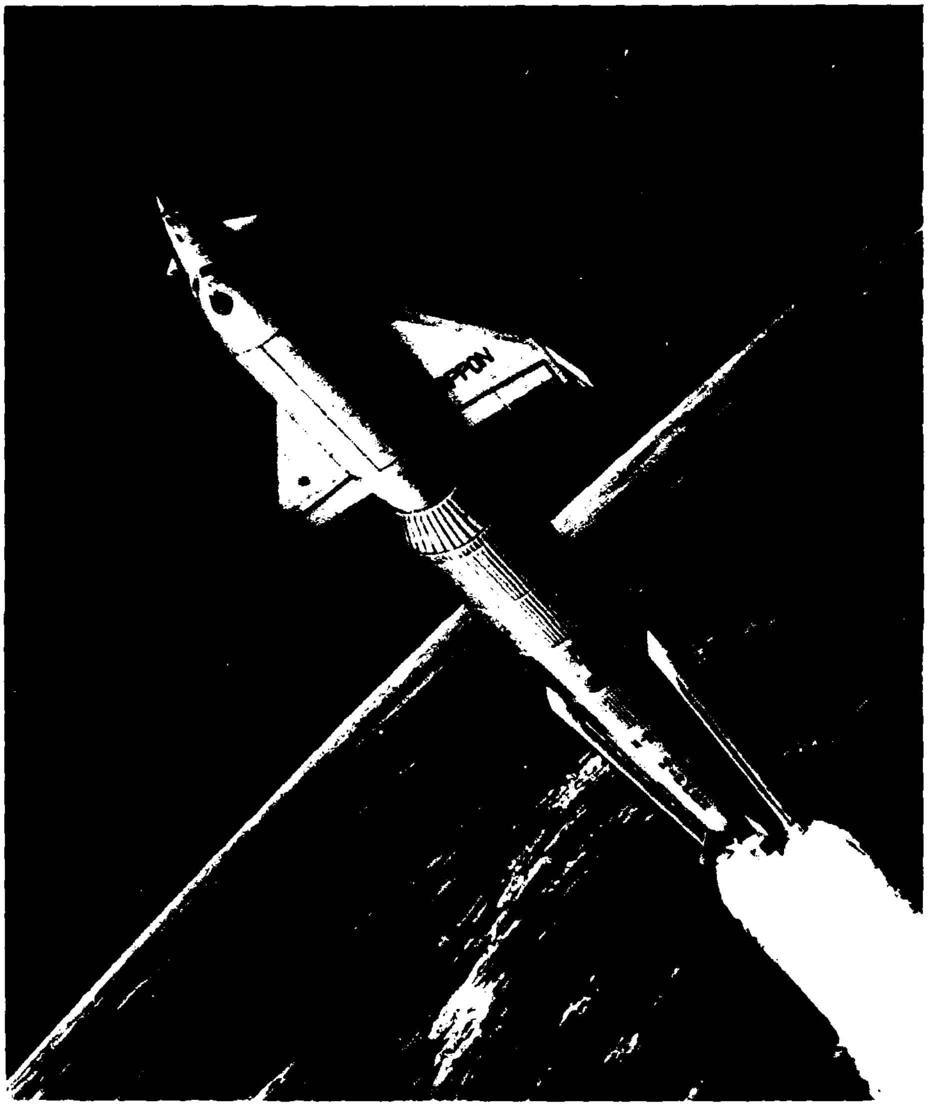
Source: DARPA

Japanese HOPE and Spaceplane

The National Space Development Agency of Japan is conducting research and development on an unmanned, fully autonomous space transportation system known as HOPE, as well as a future manned spaceplane. HOPE would be a reentry winged vehicle launched by the H-II rocket booster, also under development, from the Tanegashima Space Center in Japan. It would return to earth to land horizontally on a conventional runway. The vehicle is being designed as a fully autonomous cargo transport powered in space by rocket engines.

HOPE is being developed to provide Japan with an independent space transportation system and the ability to carry out autonomous space

Figure 4.6: Japanese HOPE



Source: National Space Development Agency of Japan

activities. HOPE is expected to provide cargo transportation to the Japanese Experiment Module to be attached to the space station and other orbiting platforms. A key objective of the HOPE program is to acquire key technologies for the future Japanese spaceplane and to conduct in-flight demonstrations for space technology experiments that could be applied to the spaceplane. HOPE is based on currently available technology.

Its first flight is scheduled for 1996, and HOPE is expected to become operational in the late 1990s. The spaceplane is not scheduled to be developed until the 21st century.

What Are the Prospects for and Desirability of International Cooperation in Developing the X-30?

NASP Program officials told us that the United States has no plans for foreign participation in developing the X-30. According to officials of the Office of Science and Technology Policy and the Department of Commerce, international cooperation in developing an aerospace plane is not desirable for political, economic, financial, technological, and legal reasons.

The NASP Program is designed to maintain U.S. technological and aeronautical leadership into the 21st century. With foreign participation, the United States may not be able to remain competitive commercially in launching payloads into orbit or in developing a commercial hypersonic transport. Much of the technological development of the X-30 is classified, and international cooperation could involve the transfer of technology that is subject to strict export controls. Finally, legal considerations could make cooperation by U.S. industry with foreign firms difficult, since foreign firms may insist on access to technology patented in the United States.

Conclusions

The X-30 has no operational mission or requirements. Potential users of the NASP Program's technology have not developed specific missions or identified firm operational requirements for future aerospace planes. Until the NASP Program has successfully developed and demonstrated the requisite technologies for future aerospace planes and the capabilities of the X-30 are determined, the identification of future missions is premature. However, the successful demonstration of sustained hypersonic cruise and single-stage-to-orbit space launch capabilities could have significant military, space, and commercial mission applications.

The X-30 experimental vehicle is being designed to demonstrate cost-effective technologies for launching payloads into orbit. For some missions, existing or planned subsonic and supersonic aircraft and space launch vehicles may be more cost-effective than an operational aerospace plane.

Environmental concerns that inhibited the development of the supersonic transport (such as the sonic boom and depletion of the ozone

layer) are unlikely to be as significant a problem in the development of a hypersonic transport.

U.S. aeronautical leadership and the national goal of maintaining aeronautical preeminence into the 21st century are being challenged by foreign countries' development of operational aerospace plane technologies. The United Kingdom, France, West Germany, the Soviet Union, and Japan are each developing technologies for their own concept of an aerospace plane to provide independent access to space and to reduce the cost of launching payloads into orbit.

The United States has no plans for foreign participation in developing the X-30. According to officials of the Office of Science and Technology Policy and the Department of Commerce, international cooperation is not desirable for political, economic, financial, technological, and legal reasons.

Comments From the Director of Defense Research and Engineering, U.S. Department of Defense

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON DC 20301-3010

3 1 [illegible] 1988

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and International
Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report, "National Aero-Space Plane: A Technology Development and Demonstration Program To Build the X-30," dated December 21, 1987, (GAO Code 392282 OSD Case 7495).

The Department concurs in all the report findings. Comments on the specific findings are attached.

The DoD response also includes comments provided by the National Aeronautics and Space Administration.

Sincerely,

Robert C. Duncan

Robert C. Duncan

Attachment

GAO DRAFT REPORT - DATED DECEMBER 21, 1987
(GAO CODE 392282) - OSD CASE 7495

"NATIONAL AERO-SPACE PLANE: A TECHNOLOGY DEVELOPMENT AND DEMONSTRATION PROGRAM TO BUILD THE X-30,"

DEPARTMENT OF DEFENSE COMMENTS

* * * * *

o FINDING A: Program Objective. The GAO reported that the objective of the National Aero-Space Plane (NASP) Program, a 3.3 billion joint DoD/National Aeronautics and Space Administration (NASA) technology development and demonstration program to build and test the X-30 experimental flight vehicle, is to develop and demonstrate the technology for hypersonic flight vehicles having technical, cost and operational advantages over existing military and commercial aircraft and space launch systems. The GAO commented that the X-30 will be designed to demonstrate sustained hypersonic cruise capability in the atmosphere at speeds between Mach 5 and 14, and at altitudes between 80,000 and 150,000 feet. According to the GAO, current aircraft cannot operate at these speeds and altitudes because there is not a suitable propulsion system. The GAO further commented that the X-30 is to demonstrate a single-stage-to-orbit space launch capability speed of up to Mach 25--orbital escape velocity. The GAO observed that, unlike the space shuttle, the X-30 would achieve Mach 25 speeds in the upper atmosphere before making a final ascent maneuver into orbit, but both shuttle and X-30 reentry into the earth's atmosphere would generally follow the same flight trajectory. The GAO concluded that the key shuttle and X-30 differences are the X-30 will (1) use an air breathing propulsion system, instead of a separate rocket booster, (2) not require external fuel tanks, (3) be able to take off horizontally, and (4) be able to make a powered landing and have maneuvering capability, if needed, during landing. (pp. 1-2, pp.9-12/GAO Draft Report)

Now on pp. 2, 10-13.

See p. 13.

DoD Response: Concur. It should be noted, however, that the primary objective is to demonstrate the single-stage-to-orbit space launch capability using air breathing propulsion since this capability in a follow-on operational space launch system will lead to on-demand, assured access to space at a significantly reduced cost-per-mission compared to other projected space launch systems.

o FINDING B: X-30 Design Goals. The GAO reported that the single-stage-to orbit capability is the most important and technically challenging X-30 design goal, and offers the highest potential NASP technologies payoff since, if successful, it could significantly reduce the costs of launching a payload into orbit as compared with the shuttle. The GAO also reported that sustained hypersonic cruise capability speed between Mach 5 and 14, allowing future hypersonic airplanes to carry out potential military missions such as interdiction, reconnaissance,

surveillance, strategic bombing and strategic airlift, as well as potential commercial missions such as long-haul passenger and cargo transportation, is the second most important X-30 design goal. The GAO observed that horizontal takeoff and landing from conventional runways capability would allow flexibility in basing a military version single-stage-to-orbit aerospace plane, increase basing survivability by eliminating U.S. reliance on just two principal space launch complexes (Cape Canaveral in Florida and Vandenberg Air Force Base in California), reduce operational and support costs and permit rapid turnaround, while from a commercial perspective, this capability is essential to permit operations from commercial airports. The GAO also observed that the X-30 design goals of achieving maximum maneuvering capability for reentry into the earth's atmosphere and powered landing capability could provide flexibility for both military and commercial missions as well as increased crew and passenger safety, could allow an operational aerospace plane to maneuver while deorbiting and landing, and also allow air controllers to handle it in a similar fashion to conventional airplanes, although some special handling procedures will be required. The GAO found that the X-30 will be an experimental vehicle, will not carry passengers or an operational payload, and will be unconstrained by specific operational missions or user requirements. The GAO also found that future operational aerospace vehicles are not a part of the NASP Program, although they are likely to be an outgrowth of it. (pp. 1-2, pp. 12-16/GAO Draft Report)

Now on pp. 2, 13-15.

DoD Response: Concur.

o FINDING C: NASP Program Schedule. The GAO found that the X-30 will be developed in three phases:

- Phase I (1982-1985). The "Copper Canyon" phase, a $5.5 million program that preceded the NASP Program, was conducted by the Defense Advanced Research Projects Agency (DARPA) with technical expertise provided by the Air Force, Navy and NASA to define an Aerospace Plane technical concept, evaluate key technologies, and identify technical risks and approaches to reduce those risks. As a result of this phase, the Secretary of Defense formally established the NASP Program in December 1985.

- Phase II (1985-1990). A concept Validation program involving developing systems, airframe structures and materials, and designing, validation and ground testing key system components, such as the propulsion system and critical airframe component structures, and conducting utility and survivability assessments. The GAO observed that Phase II is expected to cost about $0.9 billion and result in a decision, based on technologies maturity, on whether to build and test the X-30 experimental vehicle.

- Phase III (1980-1994). A program to build and test three X-30 experimental vehicles--two for transatmospheric flight testing and one for static ground testing--and continues the technology maturation process at a $2.4 billion estimated cost.

The GAO concluded that, based on the NASP Program results, a decision could be made in the mid-1990s on developing future hypersonic cruise airplanes and single-stage-to-orbit space launch vehicles. (pp. 1-2, pp. 16-18/GAO Draft Report)

Now on pp. 2, 16-17.

DoD Response: Concur.

- FINDING D: Current X-30 Development. The GAO reported that by the year 2000, space shuttle technology will be over 30 years old and strategic reconnaissance aircraft technology will be about 45 years old. The GAO also reported that during the first decade of the 21st century, the shuttle will reach--or be near--the end of its operational life. The GAO noted that, according to a NASP Program Official, the Soviet Union and other countries are also developing Aerospace Plane concepts and reusable space launch system technologies. The GAO concluded that NASP is currently being developed because significant technological advances and even breakthroughs, based on actual test data, make the X-30 development potentially achievable. (pp. 16-18/GAO Draft Report)

Now on pp. 17-18.

DoD Response: Concur.

- FINDING E: NASP Program Cost. The GAO found that the NASP Program is expected to cost more that $3.3 billion between FY 1986 and FY 1994, with the DoD planning to contribute about $2.7 billion, approximately 80 percent, and NASA planning to contribute about $675 million, approximately 20 percent. The GAO also stated that initially, funding levels for each DoD Component were identified but following Congressional direction in FY 1987, all DoD funding was consolidated into the Air Force. The GAO also found that these costs do not include DARPA's about $5.5 million "Copper Canyon" program cost between FY 1982 and FY 1985, NASA's personnel, facility and utility cost contributions estimated at about $70 million during FY 1987, or industry's about $345 million contribution during FY 1986 and FY 1987. (pp. 20-21/GAO Draft Report)

Now on pp. 18-19

See p. 18

DoD Response: Concur. Program totals are presented but NASA other funding and industry investment only address specific years, for consistency and a more complete description, NASA personnel, facility and utility cost contributions are estimated at $500 million over the program in addition to the $675 million direct contribution while industry investment is estimated at $727 million over Phase 2 of the Program.

See p. 19

The report states that separate funding levels were initially identified for each DoD component between FY 1986 and FY 1994, but beginning in FY 1988 all DoD funding for the program was consolidated in the Air Force. The report does not reflect these initial funding levels. Since the funds from each of the DoD components were subsequently transferred to the Air Force, it is important to include a summary of this original funding to fully describe the real investment of the components.

The following table provides a breakdown of the direct shares upon which the original Memorandum of Understanding was based.

	$ Millions
Air Force	$1,035
DARPA	240
Navy	520
SDIO	685
DoD Total	$2,480
NASA Total	597
Total	$3,077

o FINDING F: Joint DoD/NASA Program. According to the GAO, the NASP Program was established as a joint DoD/NASA program in December 1985, because (1) much of the required technical expertise and facilities were located throughout the country in Government departments, agencies and laboratories, as well as NASA research centers, private industry and universities, (2) DoD and NASA officials wanted to consolidate and focus Air Force, Navy, DARPA and NASA research and development in hypersonics and transatmospheric vehicles on the NASP Program, and (3) DARPA officials wanted to include potential follow-on Aerospace Plane users (Air Force, Navy, SDIO and NASA) in the program early so their needs could be considered in the X-30 design. The GAO found that the NASP Program organizational concept is a fully-integrated, joint national program described in a July 1986 DoD and NASA Memorandum of Understanding (MOU) formally assigning the DoD overall management responsibility and NASA the major role for technology maturation and lead responsibility for civilian applications. According to the GAO, the MOU established the NASP Steering Group, committed agency resources (funds, personnel, and material), affirmed the overall NASP Program objectives and resulted in DoD and NASA personnel participating jointly in all technology development, applications studies and X-30 design, fabrication and flight testing. The GAO also found that (1) the Steering Group is responsible for NASP Program policy, guidance and broad programmatic direction, but not for any future program directed toward operational systems development, and is also responsible for resolving NASP Program conflicts between the Services and agencies, (2) in 1990, the Steering Group will decide whether to proceed to Phase III, subject to Secretary of Defense and NASA Administrator consents, (3) an April 1986, internal DoD Memorandum of Agreement assigned the Air Force overall DoD program responsibility, established the management structure, committed Air Force, DARPA, Navy and SDIO resources, and established objectives, (4) A Program Management Office, (PMO) staffed by a DARPA Program Manager and Air Force, Navy and NASA Program Directors, was established in DARPA. This office is responsible for overall Phase II management and coordination, (5) All program funding, regardless of component source, is assigned to the JPO but controlled and allocated by the PMO to five program areas, (6) in January 1986, the Air Force established the NASP Joint Program Office (JPO) to implement the technical program and manage the contracts, (7) the JPO serves as the Executive Agency for DARPA during Phase II and is scheduled to become the Executive Agency for the

Air Force during Phase III, and (8) the PMO is funded by the Air Force and NASA (in FY 1986 and FY 1987, it was funded by the Navy, DARPA, and SDIO), and the PMO then allocates funding to five program areas--airframe contractors, propulsion system contractors, the technology maturation program, program administrative support, and operational utility studies. (pp. 2, pp. 24, pp. 25-29, PP. 44/GAO Draft Report)

Now on pp. 3, 22-24, 33.

DoD Response: Concur.

o FINDING G: NASP Program Management Strategy to Reduce Risk. The GAO observed that the NASP Program is technologically challenging and dependent upon the successful development and integration of several critical or enabling technologies, each requiring significant technological advances or breakthroughs. The GAO concluded that, as a result, the program faces substantial technological, programmatic and financial risks.

The GAO found that NASP Program officials have built mechanisms into the Program Management Strategy, and they should reduce some risks:

- Use of existing national assets to reduce programmatic risk. Using existing facilities, such as wind tunnels and laboratories, to minimize NASP schedule delays that would be caused by constructing new facilities, and to significantly reduce operational costs.

- Multiple technical approaches to reduce technological risks and programmatic risks. To increase the likelihood of finding a solution, and finding solutions sooner than by using only one approach.

- Competition among industry to reduce technological risks. To provide different contractor concepts.

- Use firm fixed-price contracts to minimize financial risks.

- Parallel technology maturation program and engine and airframe development programs to reduce risk in all three categories. To promote competition and provide alternatives. (pp. 2, pp. 24, pp. 29-33, pp. 44/GAO Draft Report)

Now on pp. 3, 4, 22, 25-26, 33.

DoD Response: Concur.

o FINDING H: NASP Program Schedule and Milestones. The GAO found that, although the NASP Program schedule and milestones may be achievable, little allowance was made for design and integration problems or test failures. The GAO concluded that, if any enabling technology does not mature as quickly as expected, the entire program could be delayed and its costs increased. The GAO also concluded that (1) current funding levels seem appropriate, (2) increased funding might reduce technological and schedule risks, but may not speed up technology maturation or development, (3) reduced funding could result in extending the program, could result in increased costs due to to inflation, an extended schedule and, possibly, contractors losing interest and limiting or discontinuing their investments, and (5) speeding up the program would add risks, which

could require more funding to manage. According to the GAO, a 4-month program scheduled slippage occurred in FY 1987, because of a $44 million FY 1987 appropriation reduction and only moderate design progress, and the effects were (1) a 4-month extension in Phase II milestones, (2) a $2.4 million increase in each of the five airframe contracts, and (3) a $13 million increase in each propulsion contract. The GAO noted that a 6-month schedule extension is expected in FY 1988, because of anticipated FY 1988 appropriation reductions and additional time needed to incorporate contractor component test results into engine and airframe designs. (pp.2, pp.24, pp. 33-36, pp.44/GAO Draft Report)

Now on pp. 3, 4, 22, 27-28, 33.

DoD Response: Concur.

o FINDING I: Congressional Concerns. The GAO reported that there are congressional concerns about the DoD dominating the program, the need for a major civilian component, and insufficient NASA contributions. The GAO observed that the DoD does have overall program management responsibility and plans to contribute about $241 million in FY 1988, while the NASA plans to contribute $84 million and fund $70 million in facility operation costs. The GAO found, however, that neither NASA nor NASP Program officials perceive the DoD as dominating the program or its decision process. The GAO pointed out that the NASA role is defined, its personnel and facilities are integrated into the program, and the NASA has the major role for technology maturation and lead responsibility for developing civilian applications. (pp. 4, pp. 24-25, pp. 36-37, pp. 45/GAO Draft Report)

Now on pp. 4-5, 22, 28-30, 33.

DoD Response: Concur.

o FINDING J: Incorporating Industry Investments Into Acquisition Plans. The GAO reported that industry has invested about $354 million in the NASP Program during FY 1986 and FY 1987, and plans to invest about $144 million in FY 1988, about $167 million in FY 1989, and about $63 million in FY 1990. The GAO observed that NASP contractors, however, have expressed concerns about (1) cost-sharing with no near-term product of payoff, (2) sharing their proprietary design concepts with the Government and their competitors, and (3) reporting current and projected NASP-related investments as required by the Congress. (pp. 4, pp. 25, pp. 40-45/GAO Draft Report)

Now on pp. 3, 5, 22, 31-33, 34.

DoD Response: Concur.

o FINDING K: Enabling Technologies and Their Criticality. The GAO emphasized that the enabling technologies make the Aerospace Plane concept possible, and failure to successfully develop and demonstrate any of them could adversely affect the NASP Program. In addition, the GAO emphasized that the program success depends on integrating the technologies into the X-30 experimental vehicle.

- Prepulsion System. According to the GAO, a supersonic combustion ramjet (scramjet) is being developed since the atmospheric flight envelope (speed and altitude) in which the X-30 must operate is ten times greater than current air-breathing engine technical limits, and a hydrogen fueled scramjet is believed to be the only

air-breathing engine operable at speeds up to Mach 25. The concepts include a number of low-speed propulsion options that could be used to accelerate the X-30 from take off to about Mach 3, ramjets could then be used between Mach 3 and 6, scramjets could take over between Mach 6 and 25, and rocket propulsion could be used during final ascent into orbit, for maneuvering in orbit and for deorbiting. The GAO reported that propulsion contractors have conducted studies over a range of operating conditions, developed engine design configurations, selected an approach for developing a propulsion system and are currently conducting preliminary scramjet test module design analysis, scramjet component tests and sub-scale scramjet tests. The GAO observed that this effort will end in a Test Module Review in late 1988, and the contractors then will refine their propulsion system designs and build and test a near full-scale engine module by late 1989.

- Advanced Materials. According to the GAO, engine materials must be developed that are not only high strength and lightweight, but also able to withstand extremely high temperatures and be reusable. The GAO reported that advanced materials include carbon-carbon, titanium (titanium-aluminum). The GAO reported that RST is a process in which molten titanium and aluminum are transformed into a very fine powder and then solidified, resulting in an alloy (Ti-aluminide) demonstrating much higher strength and stiffness at high temperatures (compared to conventional titanium alloys) and is half the weight of the material previously used at these high temperatures. The GAO observed that one propulsion contractor and one airframe contractor are building larger RST facilities to manufacture production-level ti-aluminide quantities.

- Thermal Control Technologies. According to the GAO, some X-30 components (such as the nose cone, wing and tail leading edges, and the inside engine combustion chamber walls) will have to be actively cooled, even though they are made of advanced heat-resistant materials. The GAO reported that a transpiration system for cooling the nose cone and leading edges is being considered. The GAO observed that NASA research centers and NASP contractors are currently developing the heat pipe transpiration technology using supercooled hydrogen to actively cool X-30 airframe and engine structures, and a ground test contractor is perfecting its platelet technology for use in a thermal control system.

- Engine/Airframe Integration. According to the GAO, (1) scramjet performance is dependent upon the flow of air entering the engine, which is affected by the X-30 forebody shape, (2) since much of the engine thrust is obtained after the exhaust leaves the engine (Exhaust pressures on the X-30 afterbody), the engine and airframe designs must be closely integrated as each will affect the other's performance. The GAO observed that much initial design work on an integrated engine/airframe has been completed, but propulsion and airframe contractors will have to work closely to design and test an integrated engine and airframe.

- Computational Fluid Dynamics and Supercomputers. According to the GAO, computational fluid dynamics--the use of advanced computer programs to solve a set of mathematical equations with a supercomputer--is used extensively in NASP Program to simulate air flows, high temperatures and pressure contours around various Aerospace Plane configuration designs are within the scramjet at the high-Mach speeds. The GAO observed that the NASP Program needs to develop computational fluid dynamic computer programs further before they are used by contractors, and a major technology maturation program effort involves improving, expanding and calibrating these computer programs against experimental data to make the programs more useable as design tools. The GAO also observed that several years may be required to develop adequate production programs.

- Efficient Use of Hydrogen. The GAO reported that efficient hydrogen uses, both as a fuel and an active component coolant, could result in (1) a fuel igniting quickly in the supersonic airflow inside the engine combustion chamber, and (2) additional space for larger payload, by eliminating the need to carry a separate cooling agent.

The GAO concluded that, even if the NASP Program does not achieve its primary objective of developing an X-30 demonstrating single-stage-to-orbit launch capability, other key objectives such as hypersonic cruise capability, key technology maturation, and technological spinoff applications may still be achievable.
Now on pp. 3, 4, 35-41, 47.
(pp. 46-58/GAO Draft Report)

DoD Response: Concur.

o FINDING L: Required Supporting Technologies. The GAO reported that supporting technologies (such as advanced avionics, artificial intelligence, and life-support systems) were developed and tested during the manned space program and more recently during the shuttle program, and new developments are not critical to the NASP Program. The GAO observed, however, that participating Government laboratories and contractors are conducting research programs into advanced avionics systems for other applications, and the results are being applied to the
Now on p. 41.
X-30. (pp. 57-58/GAO Draft Report)

DoD Response: Concur.

o FINDING M: Importance of Technical Integration. According to the GAO, the basic X-30 systems--aerodynamics (lift, drag, and control movements), thermal control (active cooling and external coatings), propulsion system (air inlet, combustor and exhaust nozzle), and structures (fuel tank, wings, tail and materials)--must be fully integrated to successfully develop the X-30, one of the first vehicles requiring almost total system integration. The GAO reported that the need to integrate the X-30 engine and airframe led to four generic designs, which now are used in aerodynamic wind tunnel and computational fluid dynamic testing, and serve as the basis for contractors to develop their own proprietary designs and measure designs performance. The GAO observed that NASA and Industry have reportedly assigned their best scientists, engineers and specialists to the NASP Program to achieve the technological advances

Now on pp. 3, 4, 35, 42-43.

required and to maintain U.S. aeronautical leadership. (pp. 58-61/GAO Draft Report)

DoD Response: Concur.

o FINDING N: Ground Test Capability Limitations. The GAO reported that (1) adequate ground test capabilities and facilities to test the X-30 above Mach 8 speed for sustained periods do not exist, and there is no single facility or group of facilities capable of creating the velocity, temperature and pressure combination necessary to simulate actual X-30 flight conditions, (2) as a result, the X-30 is being developed as a "flying test bed" to validate the requisite technologies at speeds between Mach 8 and 25, and (3) to accomplish this, ground test facilities are used to conduct various X-30 model and component test, establish a data base and validate computational fluid dynamic simulations. The GAO observed that ground tests are short duration, ground test facilities have very limited capability and productivity and are expensive to build, resulting in NASP Program plans to use existing ground test facilities to the maximum extent possible. The GAO also observed that, to validate enabling technologies by the 1990 decision milestone, the NASP Program plans to (1) develop better test techniques, (2) upgrade and modify existing ground test facilities, (3) actively pursue additional capabilities (such as reactivating, upgrading and modifying other existing facilities, or building new facilities), and (4) consider using facilities in the United Kingdom and Australia (pp. 46, pp. 61-63, pp.67/GAO Draft Report)

Now on pp. 35, 44-45, 47.

DoD Response: Concur.

o FINDING O: X-30 Manned Vehicle Development. The GAO reported that the X-30 is being developed as a manned vehicle to achieve more flexibility and system control than an automated system would yield, which is particularly important during takeoff and landing. The GAO observed that:

- in an experimental research vehicle, human pilot input is invaluable when analyzing and evaluating complex flight aspects such as stability and control, as well as propulsion control with multiple engines;

- a piloted vehicle would be more valuable than an unmanned vehicle in validating X-30 handling and transition from one speed regime to another; and

- an automated control system for an unmanned X-30 would require an extensive command, control and communication network, including ground links and satellites, since the X-30 flight range requirements could initially cover much of the continental United States.

Now on pp. 35, 46.

(pp. 46, pp. 64/GAO Draft Report)

DoD Response: Concur.

o FINDING P: Safety Features. The GAO reported that X-30 experimental vehicle flight testing, which is expected to proceed in a step-by-step process, will be risky because no vehicle has ever attempted to expand the flight envelope for air-breathing aircraft by tenfold and to demonstrate so many new technologies. According to the GAO, safety features are being incorporated into the X-30 design, including:

- a multi-engine propulsion system;
- using hydrogen fuel, resulting in less fire danger than conventional fuels, since its ignition temperature in air is 1,065 degrees fahrenheit;
- a flight control system that has four backup systems;
- a flight trajectory that is above severe weather conditions;
- the ability to make a powered landing, and maneuvering capability if a landing had to be aborted; and
- test instrumentation and monitoring systems for the engine and airframes structure.

Now on pp. 35, 46.

(pp. 46, pp. 64-66/GAO Draft Report)

DoD Response: Concur.

o FINDING Q: Potential Mission Applications. The GAO found that JPO officials began identifying potential mission applications in March 1987, and about one percent of the NASP Program funding for Phase II technology development ($8 million out of $837 million between FY 1986 and FY 1990) is allocated to identifying mission applications. The GAO concluded that a hypersonic cruise airplane with sustained high Mach speed cruise capability could have significant military, space and commercial mission applications. The GAO also concluded, however, that it would be premature to develop specific applications until the program achieves sufficient engine performance, given the vehicle weight. (pp. 68-75/GAO Draft Report)

Now on pp. 3, 4, 48-52, 60-61.

DoD Response: Concur.

o FINDING R: Alternatives to an Operational Aerospace Plane. According to the GAO, while future hypersonic flight vehicles may have technical, cost and operational advantages over existing systems, hypersonic speed may not be required for some missions, in which case existing or planned aircraft may be more cost-effective than an operational Aerospace Plane for those missions. The GAO observed that alternatives to a commercial hypersonic transport include supersonic transports, which do not require technological advances/breakthroughs or ground support facilities to handle liquid hydrogen fuel, but supersonic aircraft may have greater adverse environmental effects such as sonic boom and ozone layer depletion. The GAO also observed that other countries are developing reusable aerospace vehicles offering alternative to U.S. Aerospace Planes. (pp.75-76/GAO Draft Report)

Now on pp. 3, 48, 52-53, 60.

DoD Response: Concur.

- FINDING S: International Efforts. The GAO reported that national aeronautical research and development goals to maintain and extend U.S. aeronautical leadership and preeminence into the 21st century are challenged by foreign country operational Aerospace Plane developments, including:

  - British Horizontal Takeoff and Landing Vehicle;
  - French Hermes Spaceplane;
  - German Sanger II Advanced European Space Transportation System;
  - Soviet Aerospace Plane; and
  - Japanese HOPE and Spaceplane.

  Now on pp. 4, 48, 53-60, 61.

  (pp. 3, pp. 76-82, pp. 84/GAO Draft Report)

  DoD Response: Concur.

- FINDING T: International Cooperation. According to the GAO, the U.S. has no plan for foreign participation in the X-30 development, since international cooperation in developing an Aerospace Plane is not desirable for political, economic, financial, technological and legal reasons. The GAO observed that (1) with foreign participation, the U.S. might be unable to remain competitive commercially in launching payloads into orbit or in developing an commercial hypersonic transport, (2) much of the X-30 technology development is classified, and international cooperation could involve technology transfers subject to strict export controls, and (3) legal considerations could make U.S. and foreign country cooperation difficult, since foreign firms might insist on access to technology patented in the U.S. (pp. 3, pp. 83-84/GAO Draft Report)

  Now on pp. 4, 48, 60, 61.

  DoD Response: Concur.

RECOMMENDATIONS

- NONE:

Comments From the Acting Associate Administrator for Management, National Aeronautics and Space Administration

NASA

National Aeronautics and
Space Administration

Washington, D C
20546

Reply to Attn of RN

[illegible] 9 [illegible]

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and International
Affairs Divisions
United States General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the General Accounting Office (GAO) draft report entitled, "National Aero-Space Plane: A Technology Development and Demonstration Program to Build the X-30," (GAO Code 392282). The general consensus here at NASA is that the report is well written and is an accurate reflection of the National Aero-Space Plane (NASP) Program and the role that this agency plays.

NASA has been in touch with the NASP Program Management Office (PMO) at DARPA, and we are in general agreement with their findings. Suggested editorial changes and comments have been provided separately to Mr. Mark Pross of your staff.

NASA appreciates the interest the GAO has in the NASP program. This program will have a tremendous impact on critical technologies in aviation for years to come.

Sincerely,

S. M. Peralta
Acting Associate Administrator
for Management

Comments From the Assistant Secretary for Administration, U.S. Department of Commerce

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Administration
Washington D.C. 20230

3 FEB 1988

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and
International Affairs Division
United States General
Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This is in reply to GAO's letter of December 21, 1987 requesting comments on the draft report entitled "National Aero-Space Plane: A Technology Development and Demonstration Program to Build the X-30."

We have reviewed the enclosed comments of the Under Secretary for International Trade and believe they are responsive to the matters discussed in the report.

Sincerely,

Kay Bulow

Kay Bulow
Assistant Secretary
for Administration

Enclosure

UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary for International Trade
Washington D C 20230

0 [illegible]

Dear Mr. Conahan:

Secretary Verity asked me to comment on your draft report National Aero-Space Plane: A Technology Development and Demonstration Program to Build the X-30.

Our aerospace specialists reviewed the draft report and advised me that GAO accomplished its objectives of describing the national aero-space plane (NASP) program and the technological challenges it faces. We agree with the following statements from the report, which identify the key elements of concern:

- The NASP program faces substantial technological, programmatic, and financial risks to the Government and industry.
- The program is dependent on the successful development and integration of several critical or enabling technologies, each requiring significant advances or breakthroughs.
- The financial risks involve continuity of program funding through the Congress.

We also agree that the NASP program offers potentially high payoffs by developing hypersonic cruise capability for operational aerospace planes, furthering the application of key technologies, and providing opportunities for technological spinoffs.

Thank you for the opportunity to participate in the review of this program which has the promise of maintaining U.S. aeronautical leadership.

Sincerely,

Bruce Smart

Mr. Frank C. Conahan
Assistant Comptroller General
U.S. General Accounting Office
Washington, D.C. 20548

Comments From the Deputy Science Advisor to the President, Office of Science and Technology Policy, Executive Office of the President

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

March 3, 1988

MEMORANDUM FOR FRANK C. CONAHAN
ASSISTANT COMPTROLLER GENERAL
NATIONAL SECURITY AND INTERNATIONAL AFFAIRS DIVISION
UNITED STATES GENERAL ACCOUNTING OFFICE

FROM: DR. THOMAS P. RONA
DEPUTY SCIENCE ADVISOR TO THE PRESIDENT

Subject: GAO Draft Report - National Aero-Space Plane

The following is in answer to your request for comments on the subject document.

First, general comments. The report is well organized, clear and extremely competent. Although the report cannot discuss classified details, and did not attempt to conduct a technical assessment of the program, the reader will get a thorough picture about the program. The report wisely refrains from laudable or critical comments in regard to the future of the program.

The report raises the question of manned versus unmanned versions of the X-30 experimental vehicles. In this regard the ongoing X-30 program closely follows the Research Airplane Program (X-1-X-29), the most productive government research program of record. The manned feature has been, and should be, essential to this type of program.

Second, a number of minor comments.

Now on p. 14.

a) Page 13, second paragraph. Mention should be made of the changes in airport facilities, in particular of those involving fuel processing and handling. These are are certainly non-trivial additions both to research and to the future cost of the program.

Now on p. 15.

b) Page 15, second paragraph. The environmental compatibility should be emphasized. Because of the nature of the NASP engine combustion, the reaction creates water vapor rather than CO_2,

which in itself is desirable. The secondary noxious components such as nitrous and nitric oxides generated for high altitude flight are not in the same category, but should be examined.

Now on p. 17

c) Page 18, first paragraph. A definition of "trans-atmospheric", not found anywhere in the document, is needed.

Now on p. 19

d) Page 21. The budget figures should be updated with the latest available from DOD and NASA.

Now on p. 45

Last, one major comment (Reference to page 55).

The report may gain stature by conveying to the reader that the true emphasis in testing at high Mach numbers is for a desirable combination of four complementary techniques. The first has to do with wind tunnel and other laboratory type experiments. The second has to do with advanced computational modeling, prediction and extrapolation. The third, involves other instrumented flight tests, such as those associated with the shuttle or with unmanned missiles, and lastly the X-30, as it proceeds into the flight program.

The NASP program will emphasize an integrated investigation strategy aimed at achieving the fastest possible improvement in the *state-of-the-art* at the lowest cost with the highest possible confidence in the predictions.

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